## 10. Hydrologic/Water Quality (GLEAMS) Modeling of Illinois River Watershed

*Introduction*

The NPS P loads, including the defendants' NPS P loads, in the IRW streams and rivers and to Lake Tenkiller were modeled as described in Appendix D. A model (GLEAMS) was used to represent the details of hydrology, erosion processes and nutrient movement based on elevation, soil, rainfall, and land management data including poultry waste application to the IRW landscape. WWTP P loads were added to the NPS P loads reaching the IRW streams and rivers. P loads to streams and rivers were routed to Lake Tenkiller using a model based on stream/river flow and accumulated P in streams and rivers. The P loads to Lake Tenkiller are presented for: recent conditions (1997-2006), continuation of poultry waste land application in the IRW at current levels, cessation of poultry waste land application in the IRW, an increase in poultry waste land application based on continued growth in the poultry industry within the IRW, buffers along streams with cessation of poultry waste application in the IRW, and historical P loading (1950 to 1999) conditions. Also, an allocation among current principal sources of P loading to the surface waters of the IRW was performed.

*10.1 Modeled P for 1997 to 2006 (Actual Conditions)*

***The hydrologic/water quality model was able to accurately model the P loads to IRW rivers and streams and Lake Tenkiller.***

The P loads to the three gauging stations were modeled for 1997 through 2006 (Appendix D). This period was selected due to the increased sampling of P concentrations for runoff events that more accurately reflected P loads within the IRW. The modeled P loads (including both NPS and WWTP P) are shown in Table 10.1. Observed P loads for this period are also shown in Table 10.1. As both the modeled and observed P loads show, the loads vary greatly from year to year. This is due to the variation in weather and flows within the IRW. The flow and rainfall data for the IRW for this period and from 1950 through 2007 are shown in Figure 5.1 and Tables 5.3 and 5.4.

Table 10.1. Modeled P Load at Gauging Stations in Illinois River Watershed

| | Modeled P Load (lb) | | | | |
|---|---|---|---|---|---|
| **Year** | **Tahlequah** | **Baron Fork** | **Caney Creek** | **Total** | **Observed Total P Load (lb)** |
| 1997 | 278,955 | 61,794 | 21,874 | 362,623 | 241,107 |
| 1998 | 406,417 | 88,054 | 15,161 | 509,632 | 471,817 |
| 1999 | 430,596 | 53,139 | 7,815 | 491,550 | 450,440 |
| 2000 | 639,263 | 260,929 | 41,977 | 942,169 | 1,125,548 |
| 2001 | 386,787 | 73,015 | 26,355 | 486,157 | 592,494 |
| 2002 | 254,119 | 50,242 | 10,611 | 314,972 | 370,714 |
| 2003 | 120,477 | 6,381 | 2,993 | 129,851 | 108,276 |
| 2004 | 672,344 | 271,720 | 58,806 | 1,002,870 | 1,147,938 |
| 2005 | 333,198 | 58,829 | 12,742 | 404,769 | 340,664 |
| 2006 | 155,264 | 47,808 | 11,031 | 214,103 | 197,289 |

The point source P loads were greatly reduced beginning in 2003 due to changes in WWTP technology. However, the largest P load to Lake Tenkiller in the 1997 to 2006 period occurred in 2004. This was due to the weather and corresponding flows in that year that resulted in more NPS P load reaching Tenkiller.

The correlation between observed and modeled P loads is shown in Figure 10.1. The modeled and observed P loads exhibit a very strong correlation.

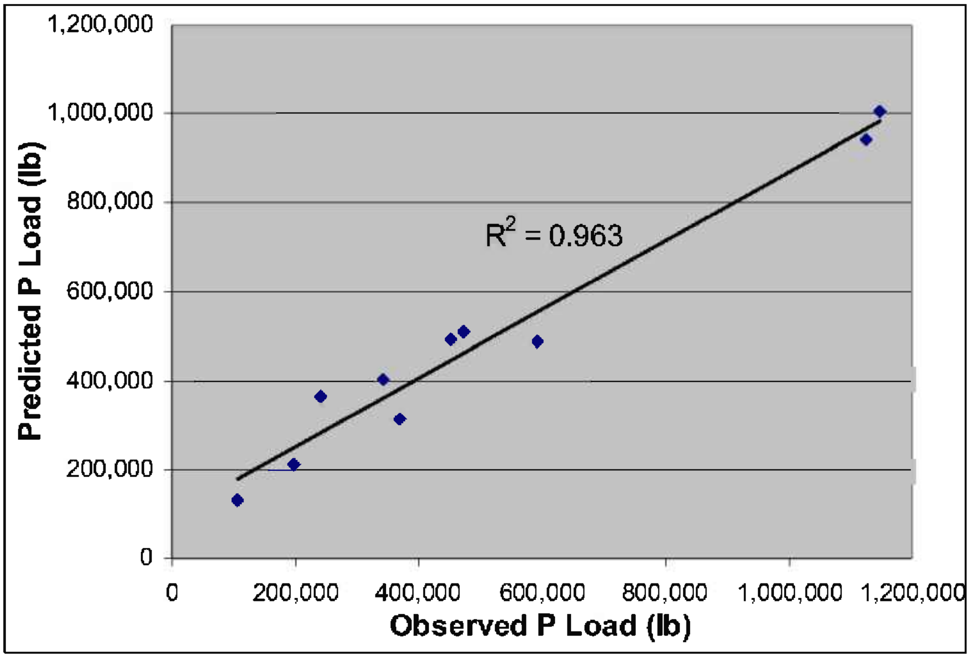


Figure 10.1. Relationship between Observed P Load and Predicted P Load to Lake Tenkiller for 1997-2006

*10.2 Modeled P for Next 100 Years with (1) Continued Poultry Waste Application and (2) Poultry Waste Cessation in the IRW*

***For continued poultry waste application in the IRW, modeled P loads to Lake Tenkiller would increase during the first 30 years. For the next 70 years, P loads to Lake Tenkiller would decline slightly and stabilize at levels above current Lake Tenkiller P loads due to P saturation of soils. Cessation of poultry waste application in the IRW would decrease P loads to Lake Tenkiller. The reductions in P loads to Lake Tenkiller due to poultry waste land application cessation are limited to 16% during the first 10 years following cessation due to continued P load contributions from historical poultry waste application in the IRW that have elevated soil P. Following poultry waste land application cessation in the IRW, reductions in P loads to Lake Tenkiller would reach 50% by years 51-60.***

The P loads at the three USGS gauging stations closest to Lake Tenkiller (Tahlequah, Baron Fork near Eldon, and Caney Creek) were modeled for (1) continued poultry waste application in the IRW and (2) cessation of poultry waste application in the IRW. The weather from 1997 to 2006 was repeated for 100 years. The modeled P loads and trend lines are shown in Figures 10.2-10.7 and in Tables 10.2-10.6.

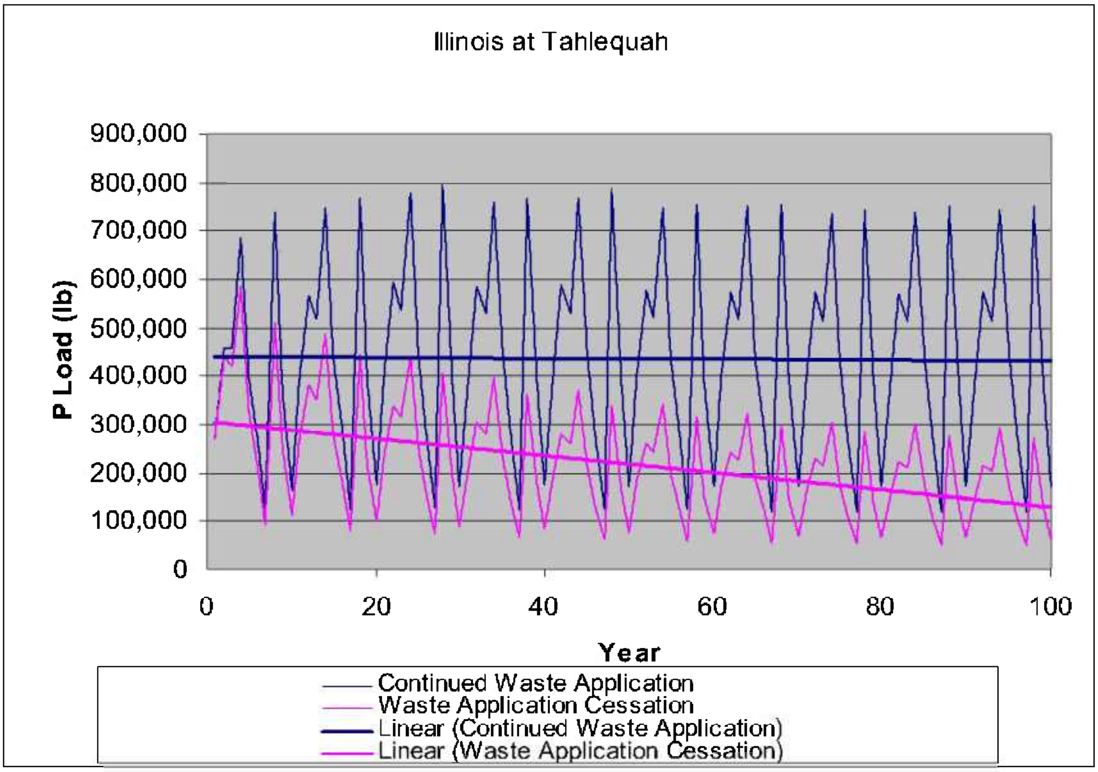


Figure 10.2. Modeled P Load at Tahlequah for Continuing Poultry Waste Application and for Cessation of Poultry Waste Application in the IRW

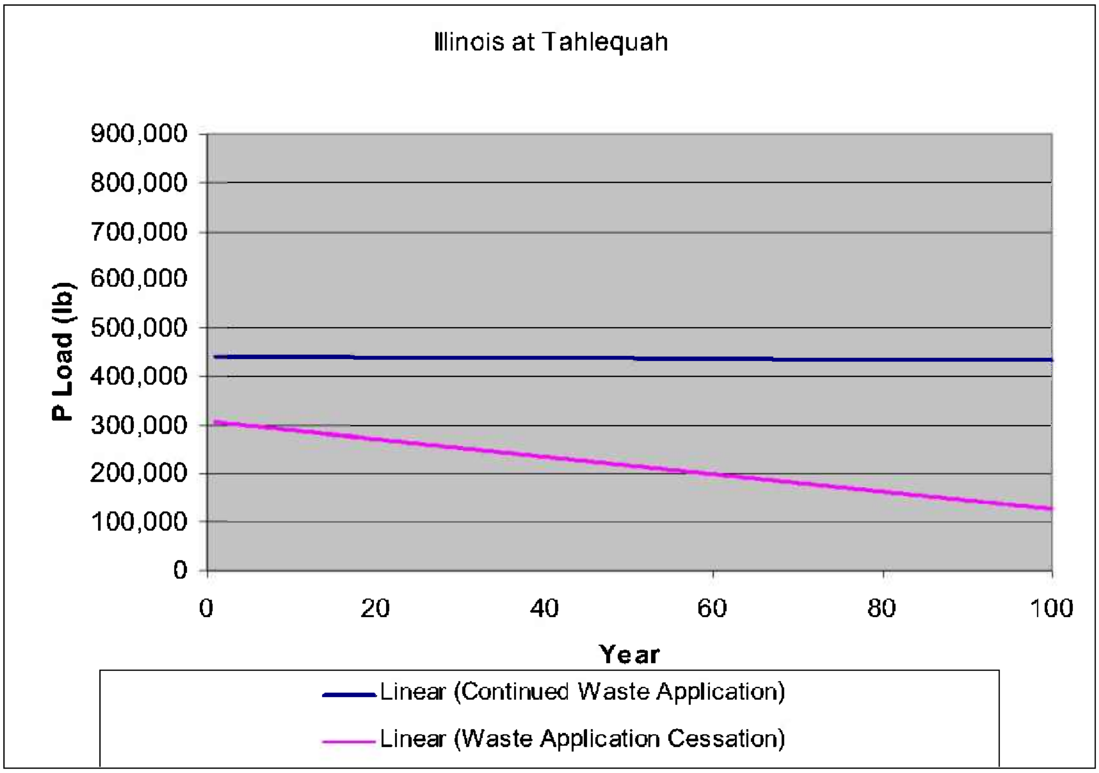


Figure 10.3 Trend Lines for Modeled P Load at Tahlequah for Continuing Poultry Waste Application and for Cessation of Poultry Waste Application in the IRW

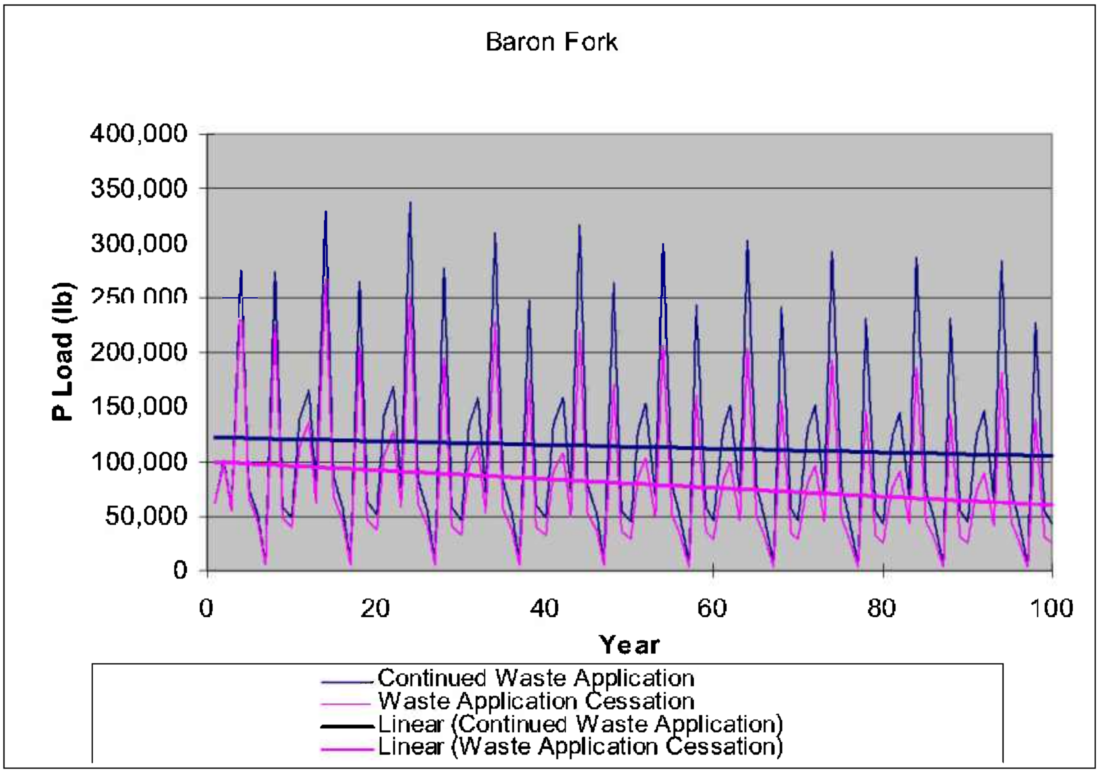


Figure 10.4. Modeled P Load at Baron Fork Gauging Station near Eldon for Continuing Poultry Waste Application and for Cessation of Poultry Waste Application in the IRW

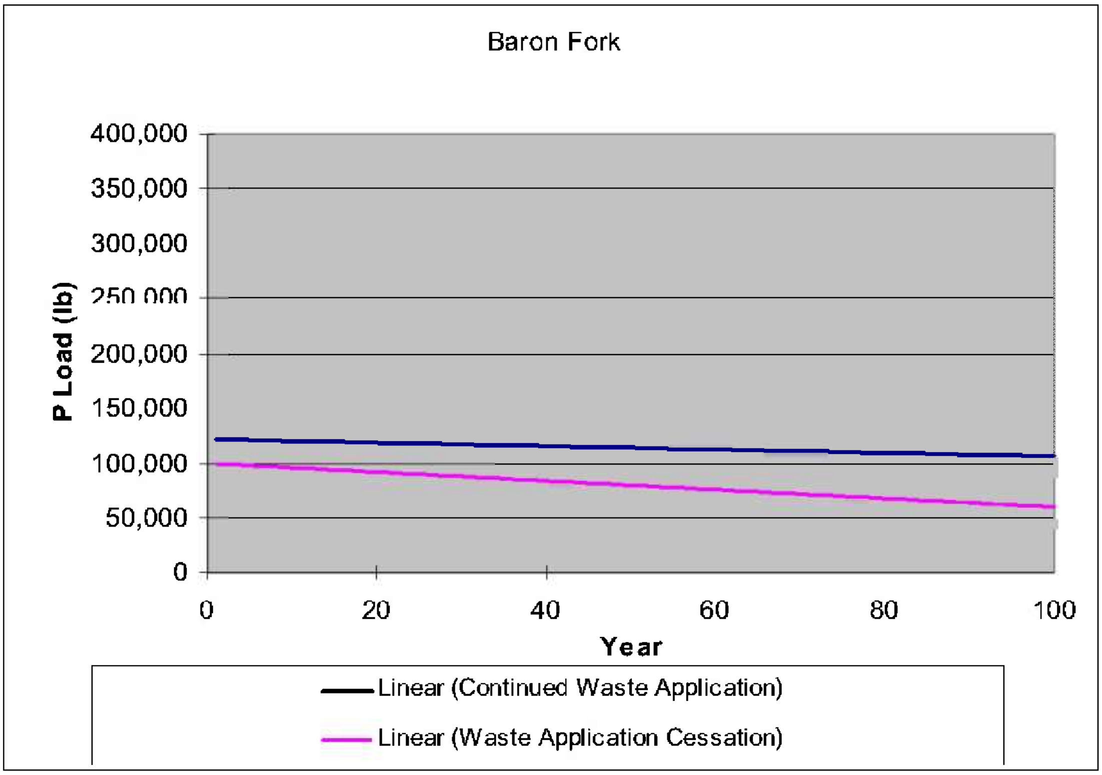


Figure 10.5 Trend Lines for Modeled P Load at Baron Fork Gauging Station Near Eldon for Continuing Poultry Waste Application and for Cessation of Poultry Waste Application in the IRW

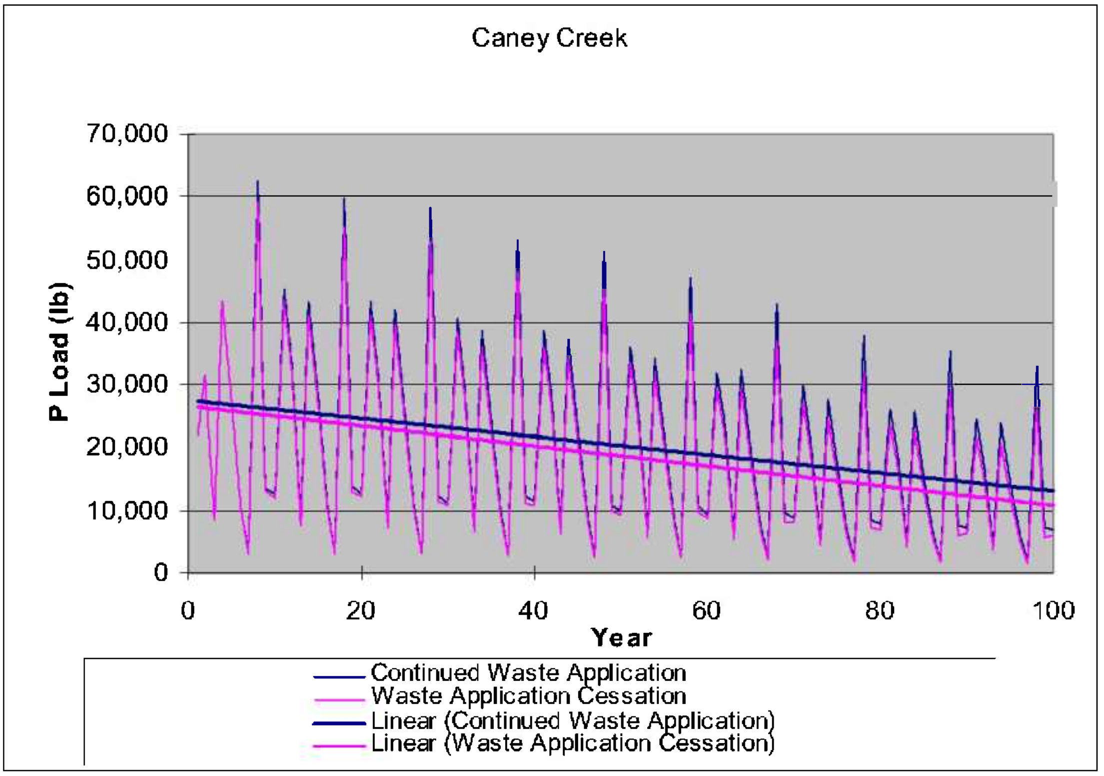


Figure 10.6 Modeled P Load at Caney Creek Gauging Station Near Eldon for Continuing Poultry Waste Application and for Cessation of Poultry Waste Application in the IRW

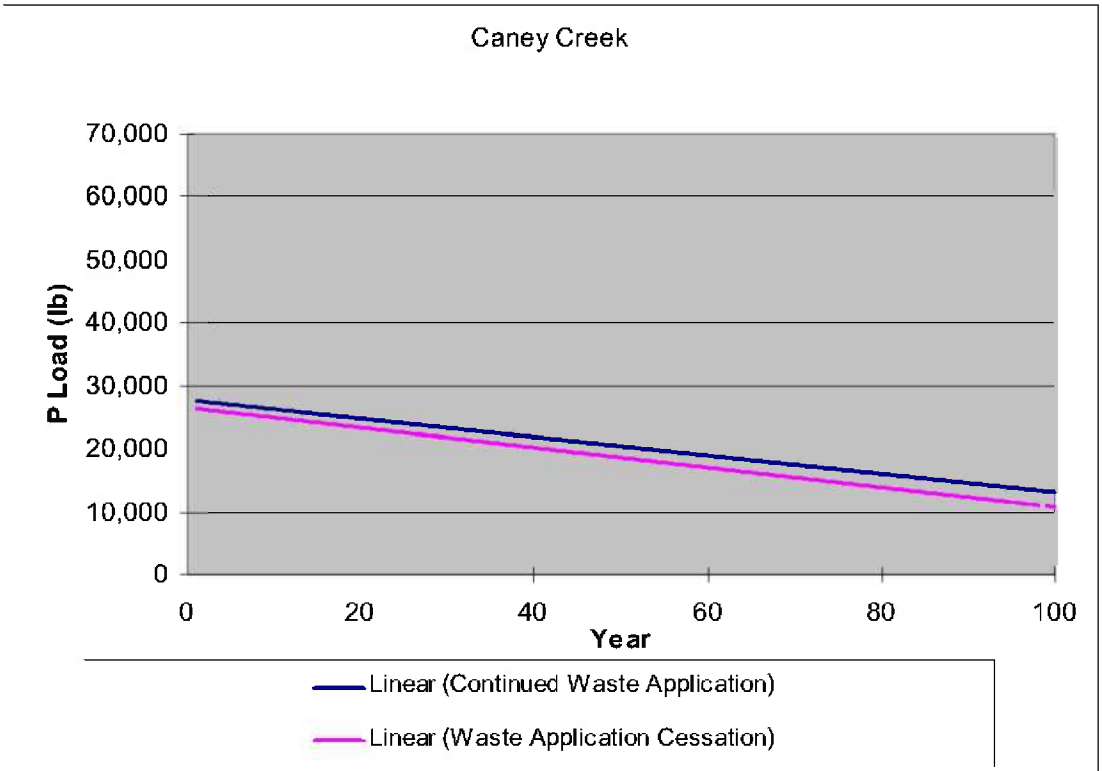


Figure 10.7. Trend Lines for Modeled P Load at Caney Creek Gauging Station near Eldon for Continuing Poultry Waste Application and for Cessation of Poultry Waste Application in the IRW

Table 10.2. Modeled P Loads at Illinois River Gauging Locations for Continued Poultry Waste Application and for Cessation of Waste Application in the IRW. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

| | **Illinois River at Tahlequah** | | **Baron Fork** | | **Caney Creek** | |
|---|---|---|---|---|---|---|
| Years | P- Continued Waste Application (lb) | P – Cessation of Waste Application (lb) | P- Continued Waste Application (lb) | P – Cessation of Waste Application (lb) | P- Continued Waste Application (lb) | P – Cessation of Waste Application (lb) |
| 1-10 | 3,927,423 | 3,216,011 | 1,012,460 | 896,907 | 234,612 | 230,567 |
| 11-20 | 4,408,574 | 2,787,287 | 1,240,857 | 987,724 | 258,152 | 244,926 |
| 21-30 | 4,548,255 | 2,509,046 | 1,251,316 | 919,733 | 245,572 | 229,875 |
| 31-40 | 4,479,081 | 2,264,368 | 1,175,349 | 837,203 | 230,505 | 214,008 |
| 41-50 | 4,489,549 | 2,094,246 | 1,183,206 | 799,781 | 217,512 | 199,793 |
| 51-60 | 4,418,033 | 1,948,115 | 1,135,476 | 761,917 | 203,549 | 185,336 |
| 61-70 | 4,401,297 | 1,831,139 | 1,136,226 | 739,856 | 185,929 | 166,473 |
| 71-80 | 4,359,942 | 1,740,937 | 1,108,147 | 703,919 | 163,384 | 143,812 |
| 81-90 | 4,365,054 | 1,693,602 | 1,083,262 | 675,952 | 149,368 | 129,298 |
| 91-100 | 4,384,281 | 1,657,713 | 1,078,687 | 661,290 | 139,019 | 118,251 |

Table 10.3. Change in P Loads to Lake Tenkiller for 10 Year Periods into the Future for Continued Poultry Waste Application and Cessation of Waste Application in the IRW. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

| Year | Total P Continued Waste (lb) | Change from Previous 10 Years (%) | Total P Waste Cessation (lb) | Change from Previous 10 Years (%) |
|---|---|---|---|---|
| 1-10 | 5,174,495 | | 4,343,485 | |
| 11-20 | 5,907,583 | 14.2 | 4,019,937 | -7.4 |
| 21-30 | 6,045,143 | 2.3 | 3,658,654 | -9.0 |
| 31-40 | 5,884,935 | -2.7 | 3,315,579 | -9.4 |
| 41-50 | 5,890,267 | 0.1 | 3,093,820 | -6.7 |
| 51-60 | 5,757,058 | -2.3 | 2,895,368 | -6.4 |
| 61-70 | 5,723,452 | -0.6 | 2,737,468 | -5.5 |
| 71-80 | 5,631,473 | -1.6 | 2,588,668 | -5.4 |
| 81-90 | 5,597,684 | -0.6 | 2,498,852 | -3.5 |
| 91-100 | 5,601,987 | 0.1 | 2,437,254 | -2.5 |

Table 10.4. Difference in P Loads to Tenkiller for Continued Poultry Waste Application Compared to Poultry Waste Application Cessation. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

| Year | Total P Continued Waste (lb) | Total P Waste Cessation (lb) | Difference (%) |
|---|---|---|---|
| 1-10 | 5,174,495 | 4,343,485 | 16.1 |
| 11-20 | 5,907,583 | 4,019,937 | 32.0 |
| 21-30 | 6,045,143 | 3,658,654 | 39.5 |
| 31-40 | 5,884,935 | 3,315,579 | 43.7 |
| 41-50 | 5,890,267 | 3,093,820 | 47.5 |
| 51-60 | 5,757,058 | 2,895,368 | 49.7 |
| 61-70 | 5,723,452 | 2,737,468 | 52.2 |
| 71-80 | 5,631,473 | 2,588,668 | 54.0 |
| 81-90 | 5,597,684 | 2,498,852 | 55.4 |
| 91-100 | 5,601,987 | 2,437,254 | 56.5 |

Table 10.5. Percentage Change in Modeled P Loads Relative to Modeled P Between 1997-2006 at Illinois River Gauging Locations for Continued Waste Application and Moratorium on Waste Application. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

| | **Illinois River at Tahlequah** | | **Baron Fork** | | **Caney Creek** | |
|---|---|---|---|---|---|---|
| Year | P Continue Waste (%) | P Stop Waste (%) | P Continue Waste (%) | P Stop Waste (%) | P Continue Waste (%) | P Stop Waste (%) |
| 1-10 | 6.8 | -12.5 | 4.2 | -7.7 | 12.1 | 10.1 |
| 11-20 | 19.9 | -24.2 | 27.7 | 1.6 | 23.3 | 17.0 |
| 21-30 | 23.7 | -31.8 | 28.7 | -5.4 | 17.3 | 9.8 |
| 31-40 | 21.8 | -38.4 | 20.9 | -13.9 | 10.1 | 2.2 |
| 41-50 | 22.1 | -43.1 | 21.7 | -17.7 | 3.9 | -4.6 |
| 51-60 | 20.1 | -47.0 | 16.8 | -21.6 | -2.8 | -11.5 |
| 61-70 | 19.7 | -50.2 | 16.9 | -23.9 | -11.2 | -20.5 |
| 71-80 | 18.6 | -52.7 | 14.0 | -27.6 | -22.0 | -31.3 |
| 81-90 | 18.7 | -53.9 | 11.5 | -30.5 | -28.7 | -38.2 |
| 91-100 | 19.2 | -54.9 | 11.0 | -32.0 | -33.6 | -43.5 |

Table 10.6. Percentage Change in Modeled P Loads Relative to Observed P Between 1997-2006 at Illinois River Gauging Locations for Continued Waste Application and Cessation of Waste Application. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

| | **Illinois River at Tahlequah** | | **Baron Fork** | | **Caney Creek** | |
|---|---|---|---|---|---|---|
| Year | P – Continued Waste (%) | P – Waste Cessation (%) | P – Continued Waste (%) | P – Waste Cessation (%) | P – Continued Waste (%) | P – Waste Cessation (%) |
| 1-10 | 7.0 | -12.4 | -12.8 | -22.8 | 8.8 | 6.9 |
| 11-20 | 20.1 | -24.0 | 6.9 | -14.9 | 19.7 | 13.6 |
| 21-30 | 23.9 | -31.6 | 7.8 | -20.8 | 13.9 | 6.6 |
| 31-40 | 22.1 | -38.3 | 1.2 | -27.9 | 6.9 | -0.8 |
| 41-50 | 22.3 | -42.9 | 1.9 | -31.1 | 0.9 | -7.3 |
| 51-60 | 20.4 | -46.9 | -2.2 | -34.4 | -5.6 | -14.1 |
| 61-70 | 19.9 | -50.1 | -2.1 | -36.3 | -13.8 | -22.8 |
| 71-80 | 18.8 | -52.6 | -4.6 | -39.4 | -24.2 | -33.3 |
| 81-90 | 19.0 | -53.8 | -6.7 | -41.8 | -30.7 | -40.0 |
| 91-100 | 19.5 | -54.8 | -7.1 | -43.0 | -35.5 | -45.2 |

For continued poultry waste application, the P loads at Tahlequah increase slightly for the first 30 years before stabilizing and declining slightly in subsequent years. Thus, the trend line for P loads at Tahlequah is flat. The P load results for continued poultry waste application for the Baron Fork location are similar to those at Tahlequah. The Baron Fork and Tahlequah results indicate the IRW soils in these watersheds have reached their capacity to retain additional P and thus expected P losses increase slightly over time before stabilizing and decreasing slightly. The P loads from these watersheds has reached steady state for current poultry waste land application. Note however, that tremendous variability in P loads from year to year exists due to variability in rainfall and flows in IRW streams and rivers.

The P loads for Caney Creek for continued poultry waste application decline due to the small amount of poultry waste applied in this watershed and the low STP values for soils in this watershed. More P is removed from this watershed than is applied with the poultry waste.

The P loads at Tahlequah and Baron Fork near Eldon would likely be greater than modeled loads under the continued poultry waste application scenario. The historical flows from 1950 through 2007 in the IRW were greater than flows for 1997 to 2006 (the period used for modeling the future). P loads to Tenkiller are strongly correlated with flow (Vieux and Moreda, 2003). Thus, if the weather for 1950 through 2007 repeats in the future, the P loads into Lake Tenkiller would be greater than modeled loads using 1997 through 2006 weather and flow data.

The P loads and trends for cessation of poultry waste application are shown in Figures 10.2-10.7 and Tables 10.2-10.6.

The P loads decrease by more than 16% in the first 10 years for IRW poultry waste application cessation compared to continued poultry waste application (Table 10.4 and Figure 10.8). The results indicate that poultry waste land application cessation within the IRW would provide some benefit (16% reduction in P loads to Lake Tenkiller). However, more than 70 years would be required for the P loads to be reduced to 50% of their current levels. This is due to the significant amount of P stored in the soils within the IRW as indicated by STP levels and the IRW P mass balance described in Appendix B. The large amount of P from land application of poultry waste continues to contribute to P loads reaching Tenkiller at substantial levels into the future. Even at 100 years, the accumulated P from poultry waste application continues to significantly contribute to P loads.

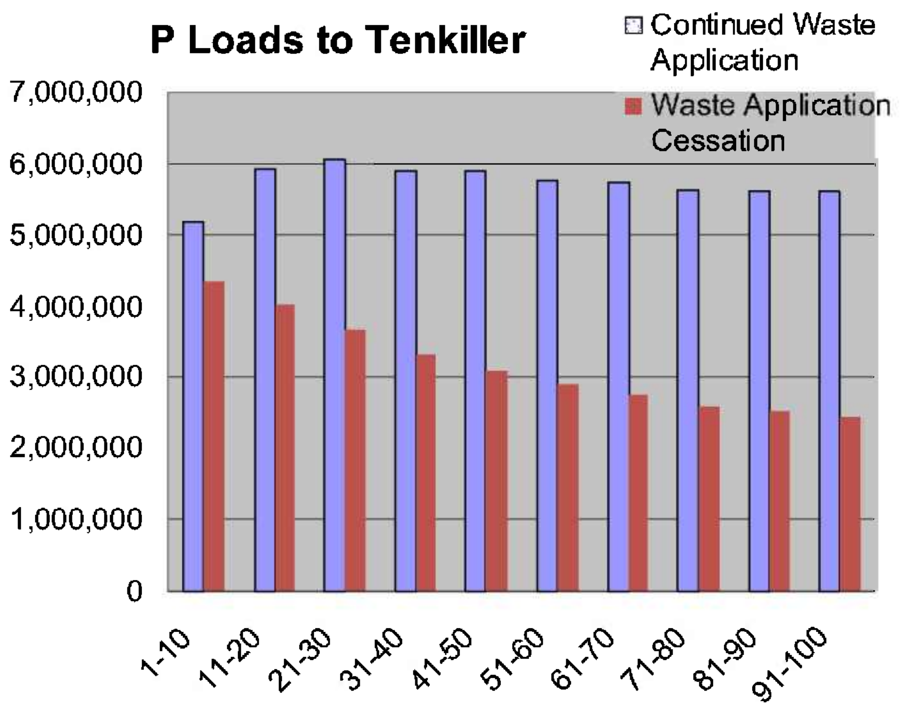


Figure 10.8. P Loads to Lake Tenkiller for Continued Waste Application in the IRW. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

*10.3 P Loads for Increased Poultry Waste Application*

***For continued growth in the IRW poultry industry at a rate the same as that between 1982 and 2002, P loads to Lake Tenkiller would increase substantially. Within 40-50 years, P loads to Lake Tenkiller would nearly double (increase of 92%).***

Figures 10.9-10.14 show P loads at each of the three gauging stations (Tahlequah, Baron Fork at Eldon and Caney Creek) for continued growth in IRW poultry based on the same rate of growth between 1982 and 2002 based on the USDA Agricultural Census poultry data. Figures 10.15 and 10.16 show P loads to Lake Tenkiller for this same situation. Based on this rate of growth assumption, P loads to Lake Tenkiller through the Tahlequah location would increase substantially (double in 40-50 years) as a result of increased poultry waste application in this watershed. P load changes at the Baron Fork location would increase a smaller amount (60% in 40-50 years) due to less poultry waste being applied in this watershed. P loads at the Caney Creek location would decrease slightly over time (50 years) in this scenario (but less than no changes in poultry production) due to the small amount of poultry waste applied in this watershed and the low STP levels.

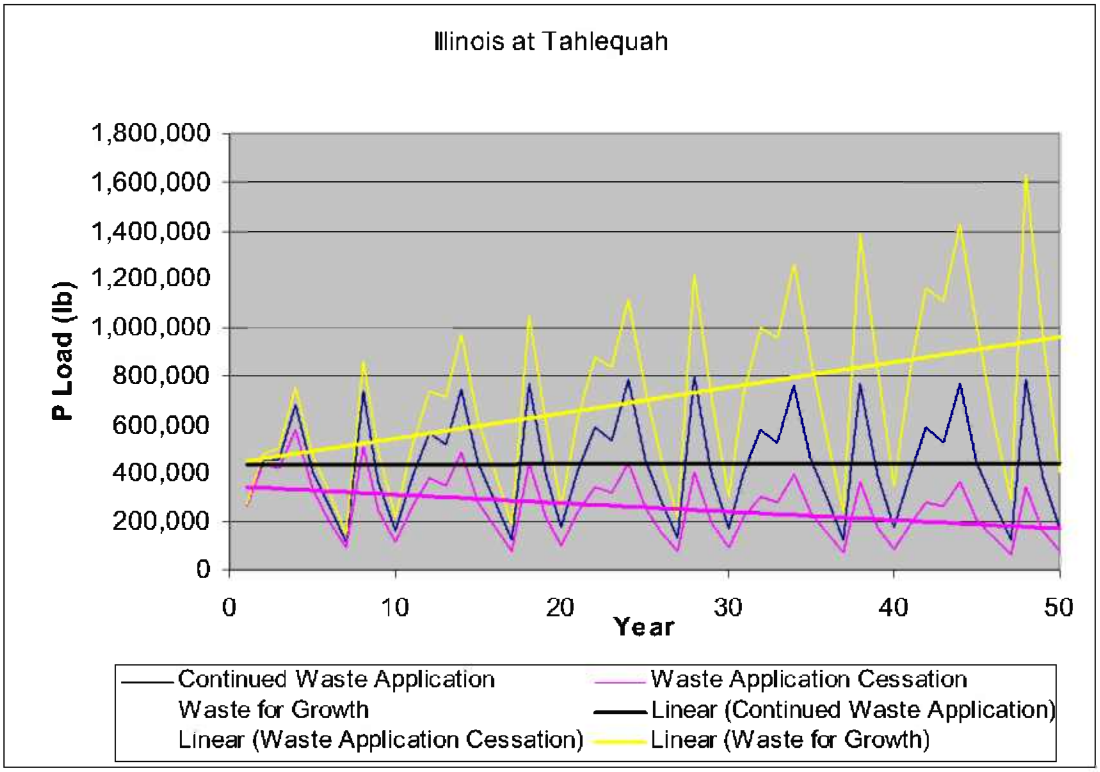


Figure 10.9. P Loading and Trend Lines at Tahlequah for Continued Waste Application, Waste Application Cessation, and Growth in Waste Application Modeled after Poultry Growth in IRW between 1982 and 2002 Based on Ag Census Data

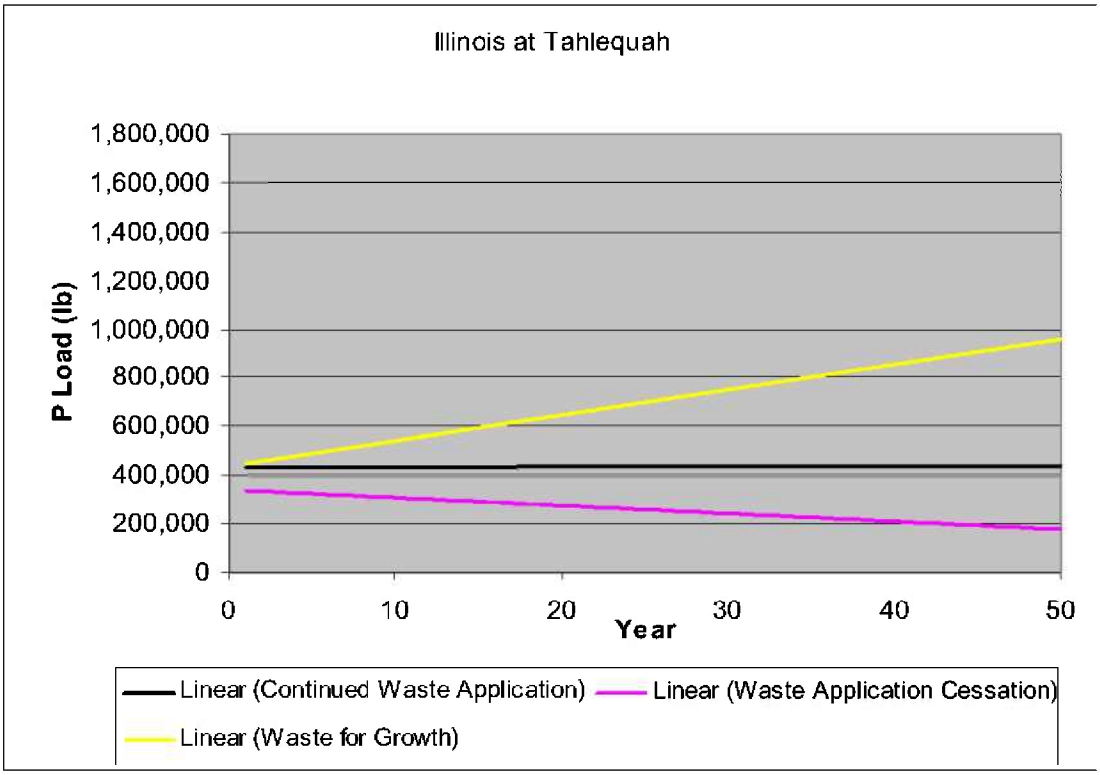


Figure 10.10. P Loading Trend Lines at Tahlequah for Continued Waste Application, Waste Application Cessation, and Growth in Waste Application Modeled after Poultry Growth in IRW between 1982 and 2002 Based on Ag Census Data

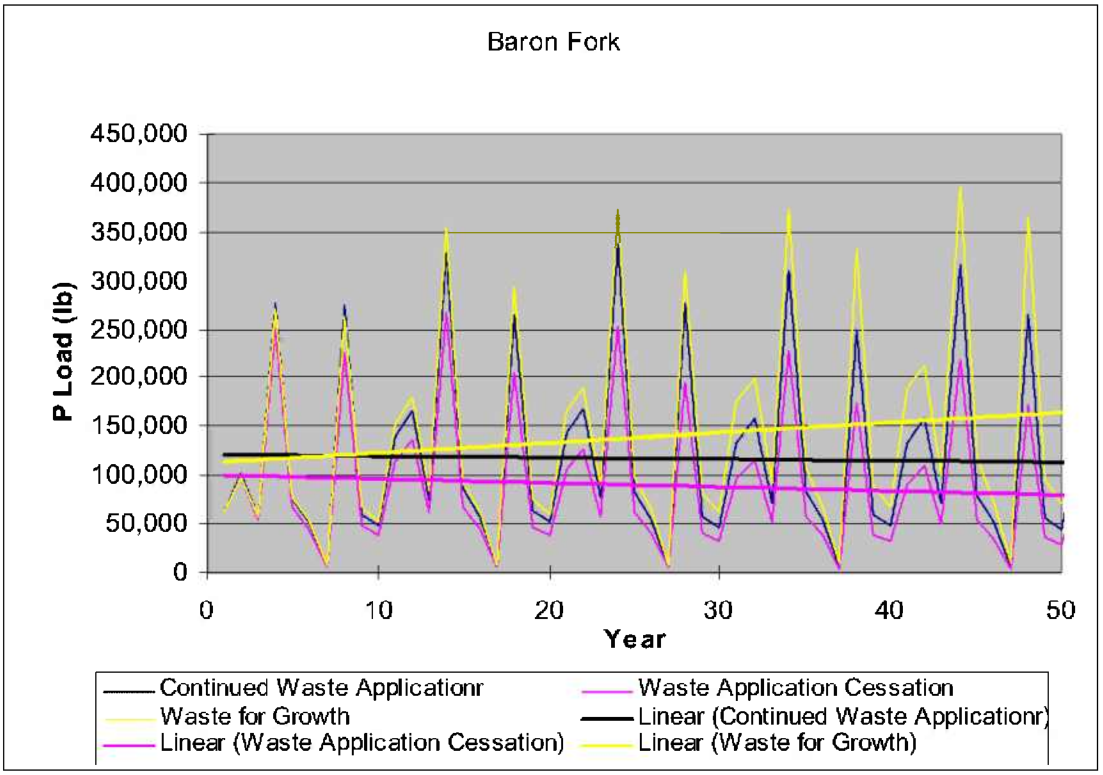


Figure 10.11. P Load and Trend Lines at Baron Fork near Eldon for Continued Waste Application, Waste Application Cessation, and Growth in Waste Application Modeled after Poultry Growth in IRW between 1982 and 2002 Based on Ag Census Data

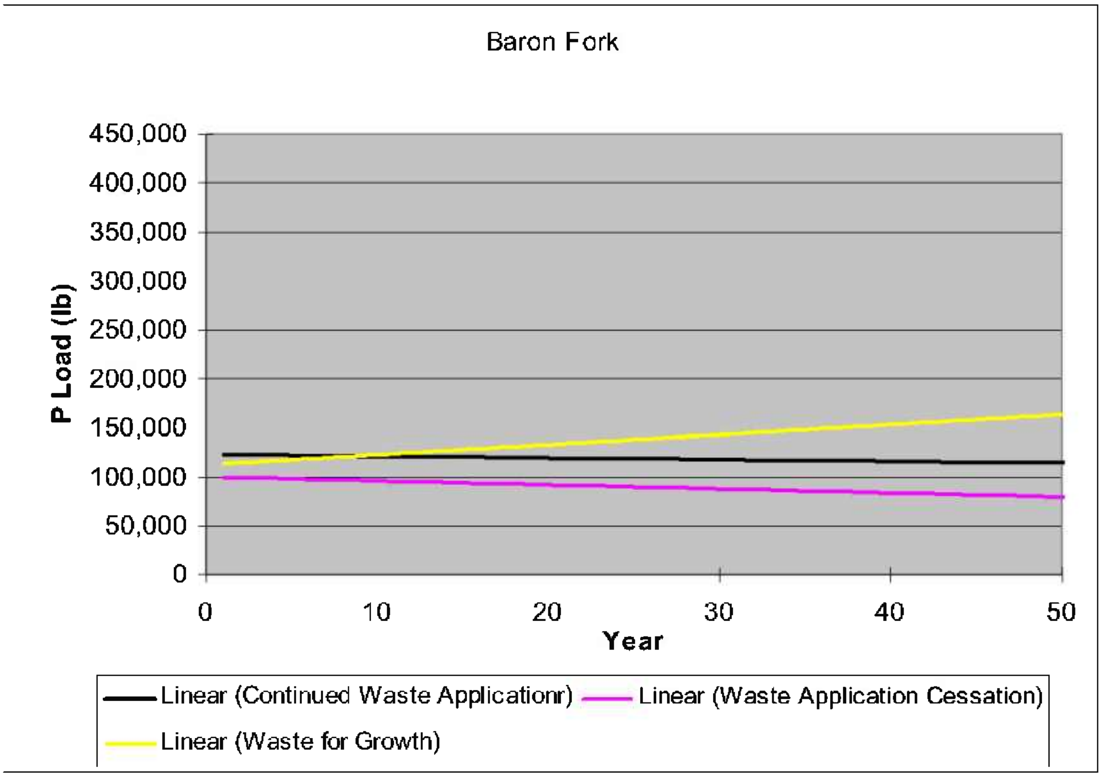


Figure 10.12. P Load Trend Lines at Baron Fork near Eldon for Continued Waste Application, Waste Application Cessation, and Growth in Waste Application Modeled after Poultry Growth in IRW between 1982 and 2002 Based on Ag Census Data

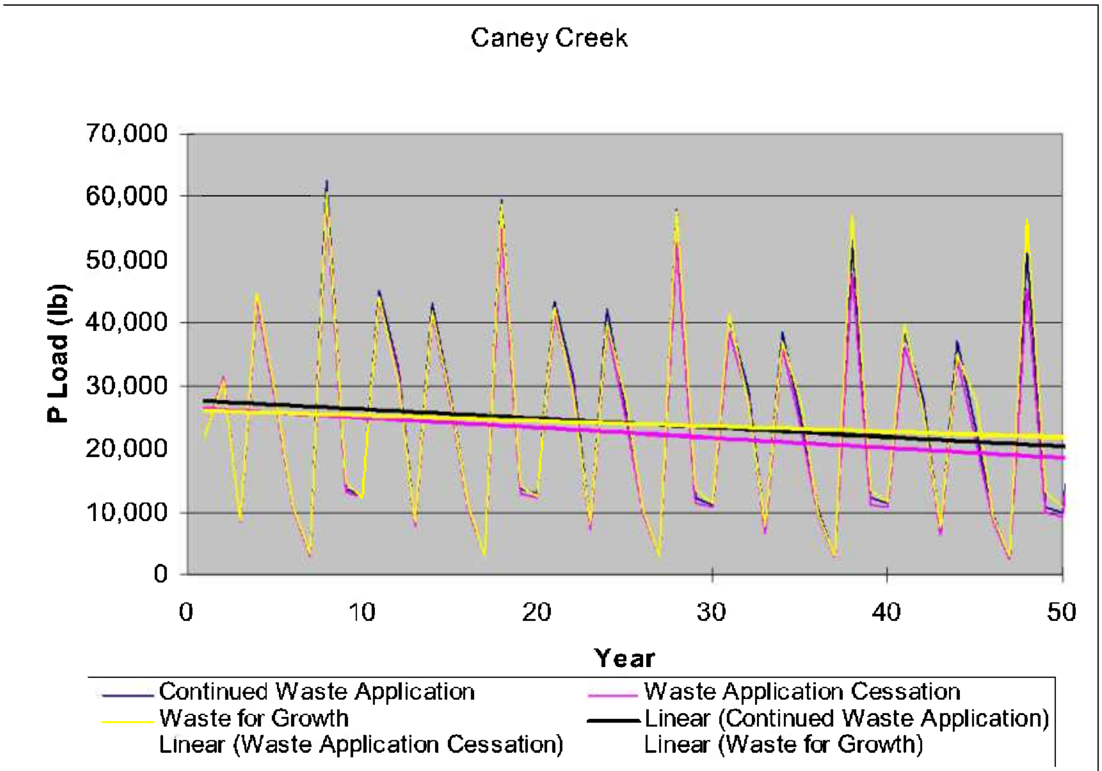


Figure 10.13. P Load and Trend Lines at Caney Creek for Continued Waste Application, Waste Application Cessation and Growth in Waste Application Modeled after Poultry Growth in IRW between 1982 and 2002 Based on Ag Census Data

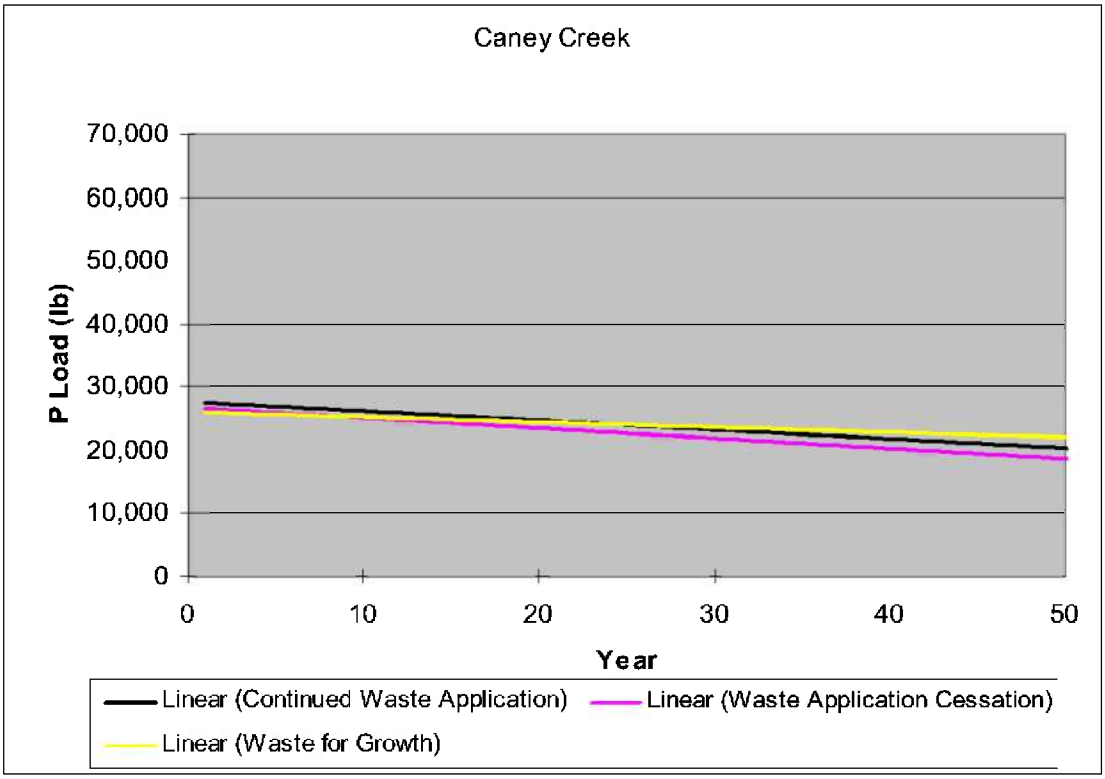


Figure 10.14. P Load Trend Lines at Caney Creek for Continued Waste Application, Waste Application Cessation and Growth in Waste Application Modeled after Poultry Growth in IRW between 1982 and 2002 Based on Ag Census Data

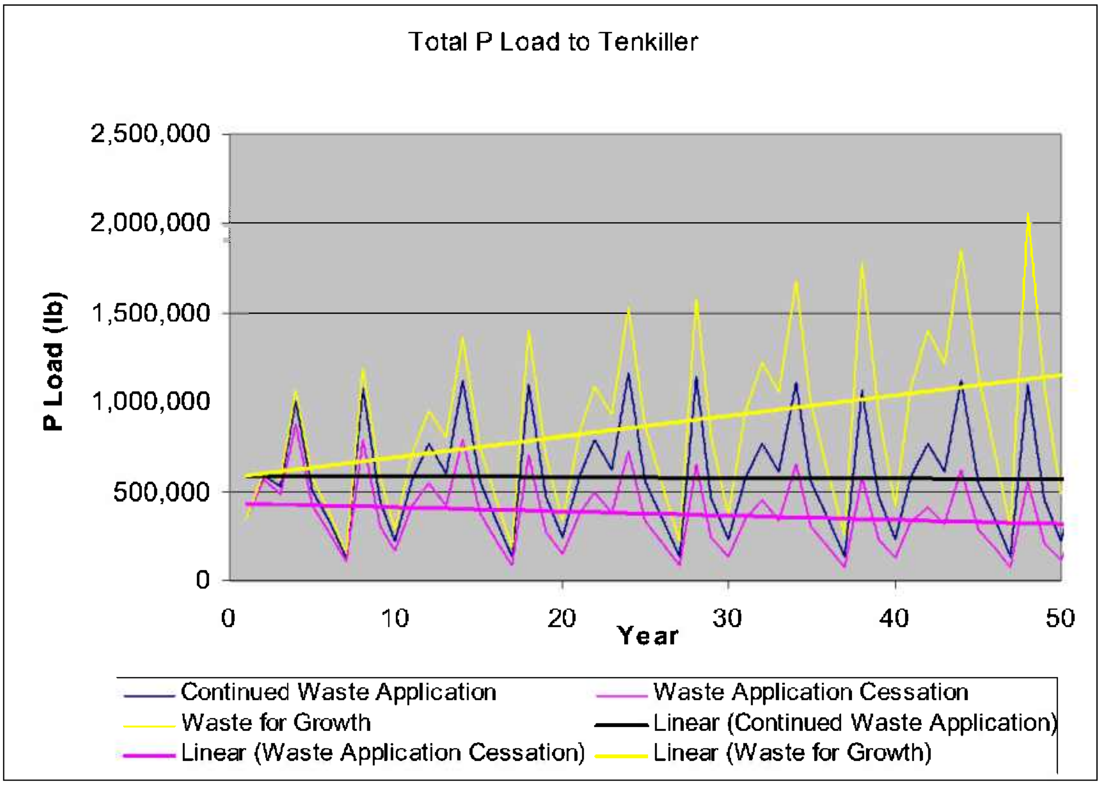


Figure 10.15. P Load and Trend Lines to Lake Tenkiller for Continued Waste Application, Waste Application Cessation and Growth in Waste Application Modeled after Poultry Growth in IRW between 1982 and 2002 Based on Ag Census Data

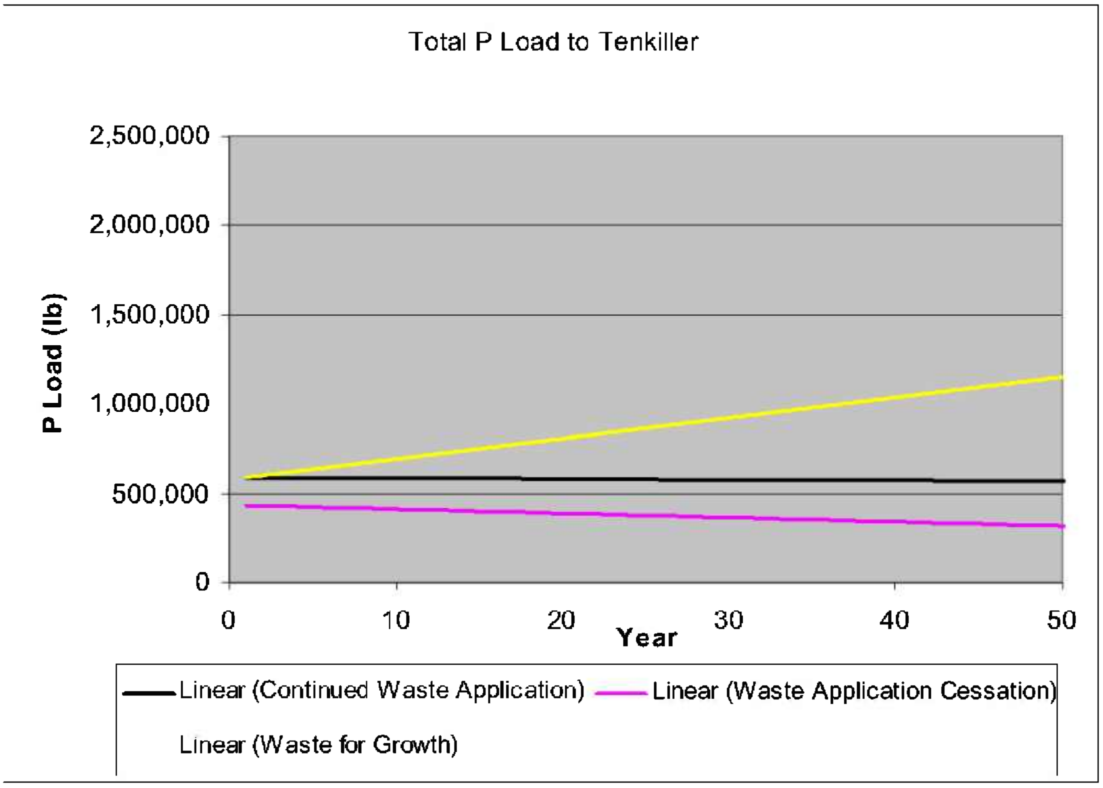


Figure 10.16. P Load Trend Lines to Lake Tenkiller for Continued Waste Application, Waste Application Cessation and Growth in Waste Application Modeled after Poultry Growth in IRW between 1982 and 2002 Based on Ag Census Data

Table 10.7 shows individual main stream and total P loads to Lake Tenkiller for the poultry growth scenario compared to current poultry production and waste application P loads. Growth in the poultry industry in the IRW and the associated land application of this waste in the IRW would result in greatly increased P loads to Lake Tenkiller that nearly double in the 40-50 year time frame.

Table 10.7. P Loads for Growth in IRW Poultry Compared to P Load for Poultry Waste Applied to IRW at Current Rates. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

| | **P Load (lb) for Growth in Poultry in IRW** | | | | **P Load (lb)** | |
|---|---|---|---|---|---|---|
| Years | Tahlequah | Baron Fork | Caney | Total | Total Continued Waste | Increase (%) |
| 1-10 | 4,523,331 | 1,010,394 | 235,614 | 5,769,339 | 5,174,495 | 11.5 |
| 11-20 | 6,066,771 | 1,364,064 | 252,099 | 7,682,934 | 5,907,583 | 30.1 |
| 21-30 | 7,112,706 | 1,439,913 | 243,753 | 8,796,372 | 6,045,143 | 45.5 |
| 31-40 | 8,144,070 | 1,512,312 | 235,329 | 9,891,711 | 5,884,935 | 68.1 |
| 41-50 | 9,464,415 | 1,635,132 | 228,607 | 11,328,153 | 5,890,267 | 92.3 |

*10.4 P Loads for Buffers and Poultry Waste Land Application Cessation*

***The addition of vegetated 100 foot buffers along all 3rd order and larger IRW streams combined with poultry waste application cessation in the IRW would provide further reductions of P loads of between 3 and 5% compared to poultry waste application cessation alone. The addition of vegetated 100 foot buffers along all IRW streams combined with poultry waste application cessation in the IRW would provide further reductions of P loads of between 10 and 13% compared to poultry waste application cessation alone.***

P loads were calculated for three locations entering Lake Tenkiller (Tahlequah, Baron Fork at Eldon, and Caney Creek) for combined poultry waste land application cessation and 100 foot buffers placed along 3rd order and larger streams and rivers with adjacent pasture. The P loads for each of these locations are shown in Figures 10.17-10.22. The buffers would provide a modest 4-5% additional reduction (see Table 10.8 and Figure 10.23) in P loads to Lake Tenkiller relative to land application of poultry waste cessation alone as depicted in Figures 10.17-10.23.

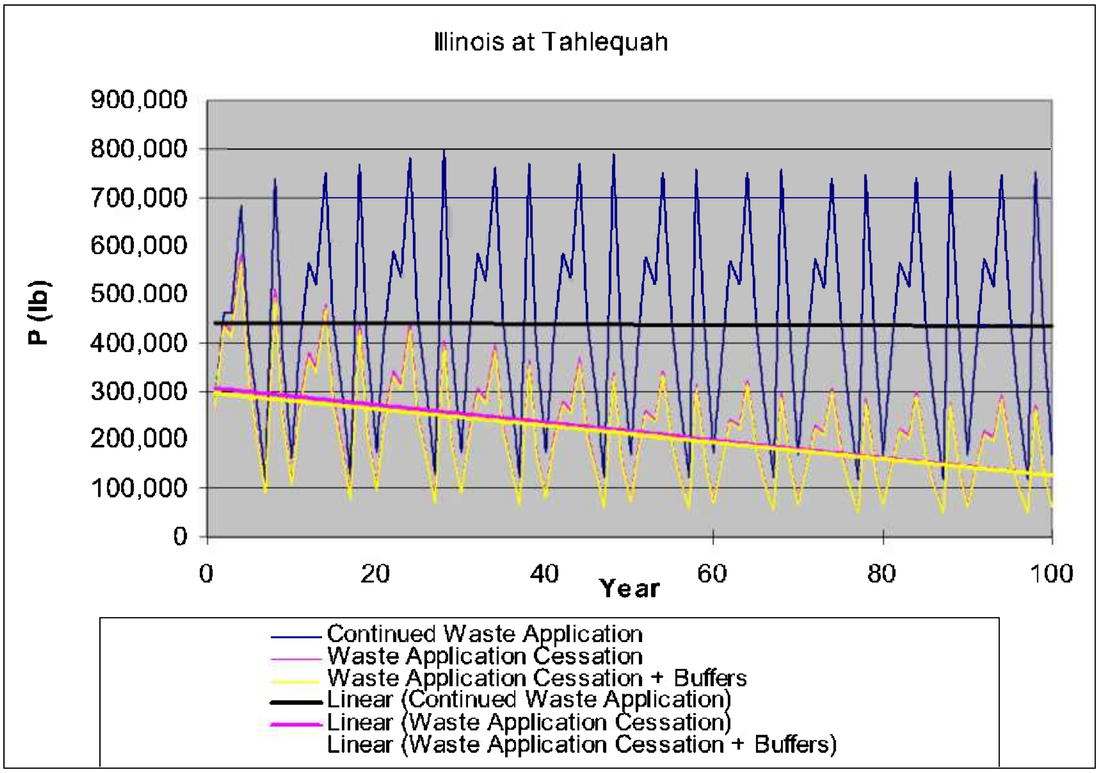


Figure 10.17. P Loads at Tahlequah for the Combination of Buffers Along Third Order and Larger Streams and Rivers and Poultry Waste Land Application Cessation in the IRW.

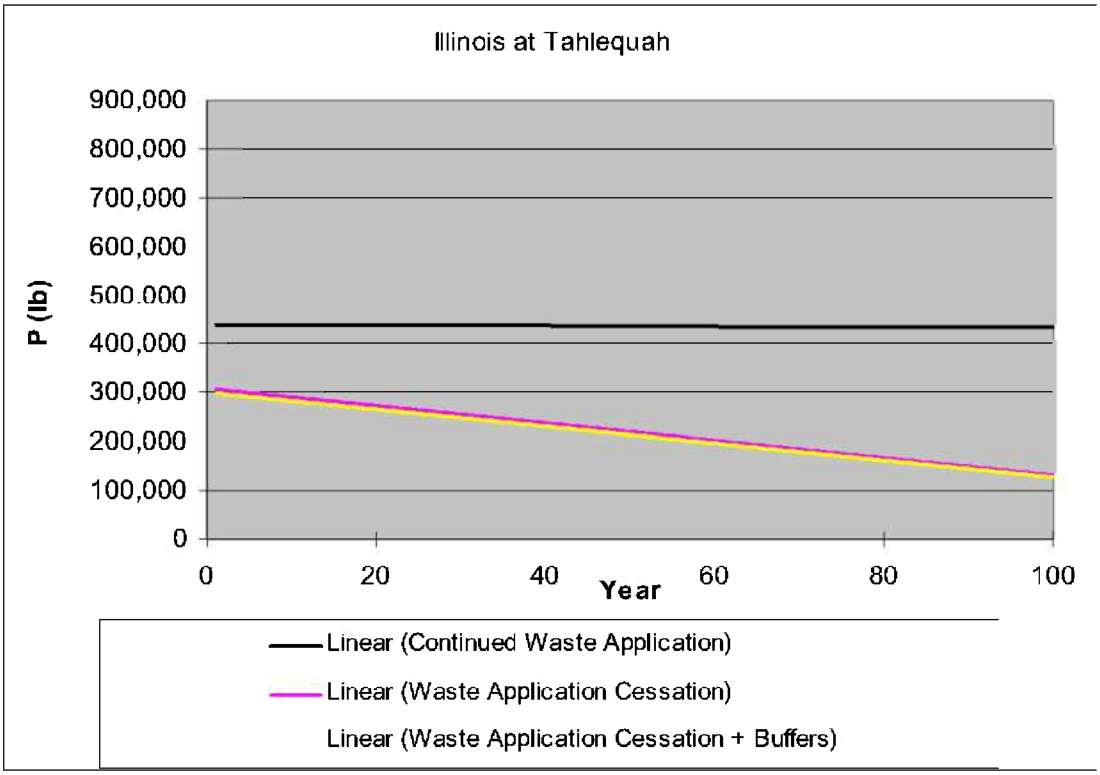


Figure 10.18. P Load Trend Lines at Tahlequah for the Combination of Buffers Along Third Order and Larger Streams and Rivers and Poultry Waste Land Application Cessation in the IRW.

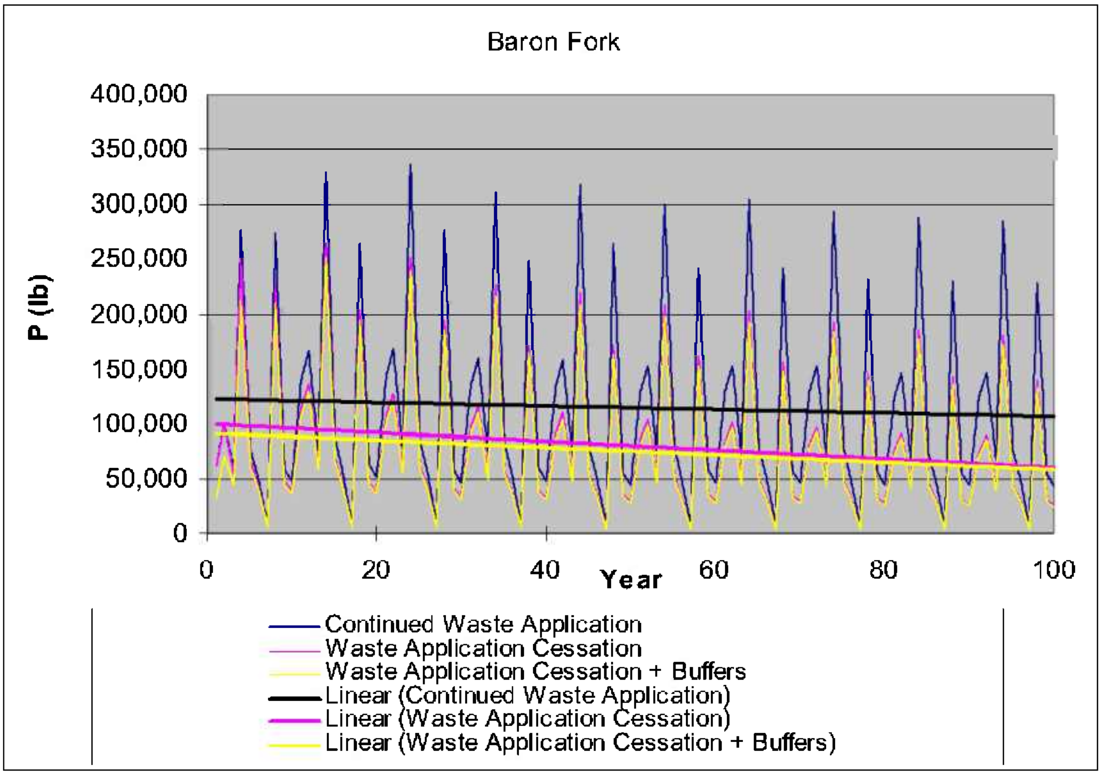


Figure 10.19. P Loads at Baron Fork Near Eldon for the Combination of Buffers Along Third Order and Larger Streams and Rivers and Poultry Waste Land Application Cessation in the IRW.

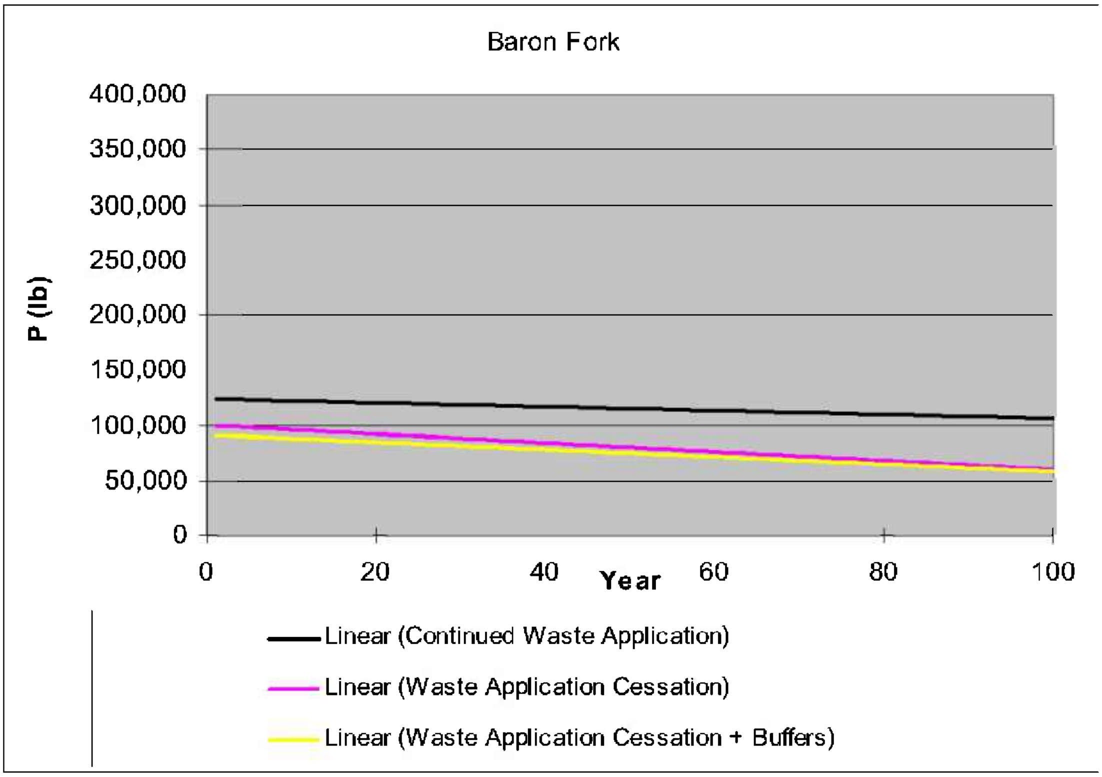


Figure 10.20. P Load Trend Lines at Baron Fork Near Eldon for the Combination of Buffers Along Third Order and Larger Streams and Rivers and Poultry Waste Land Application Cessation in the IRW.

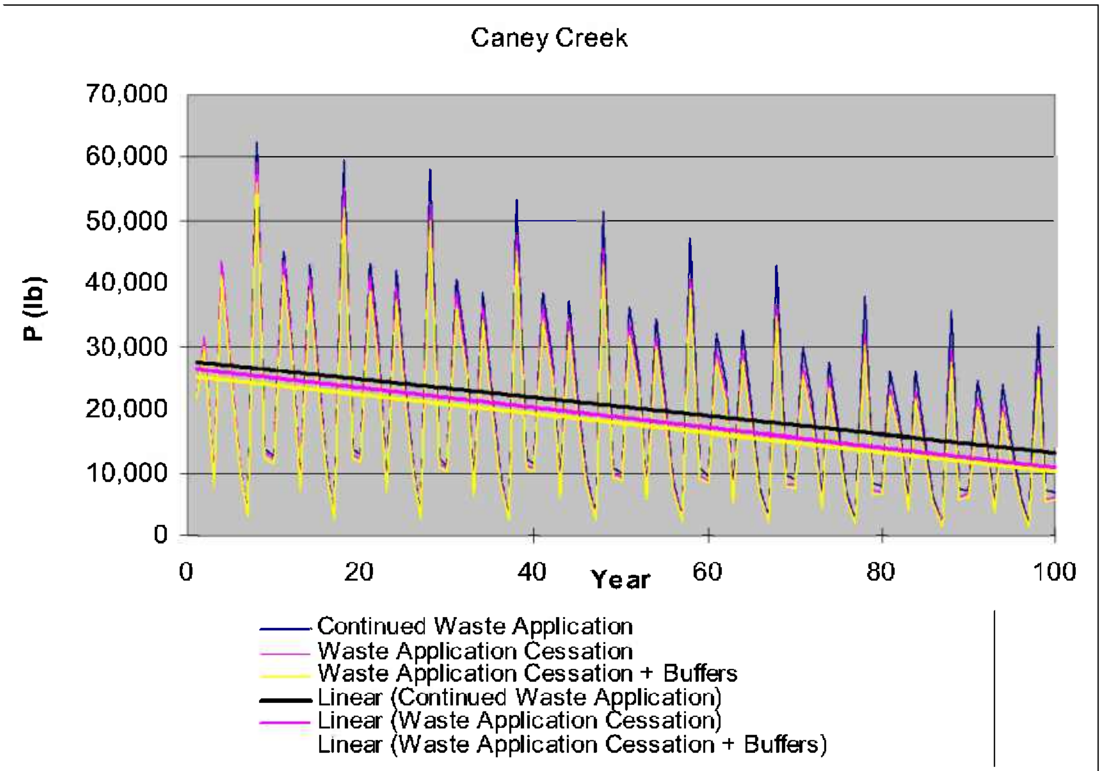


Figure 10.21. P Loads at Caney Creek for the Combination of Buffers Along Third Order and Larger Streams and Rivers and Poultry Waste Land Application Cessation in the IRW.

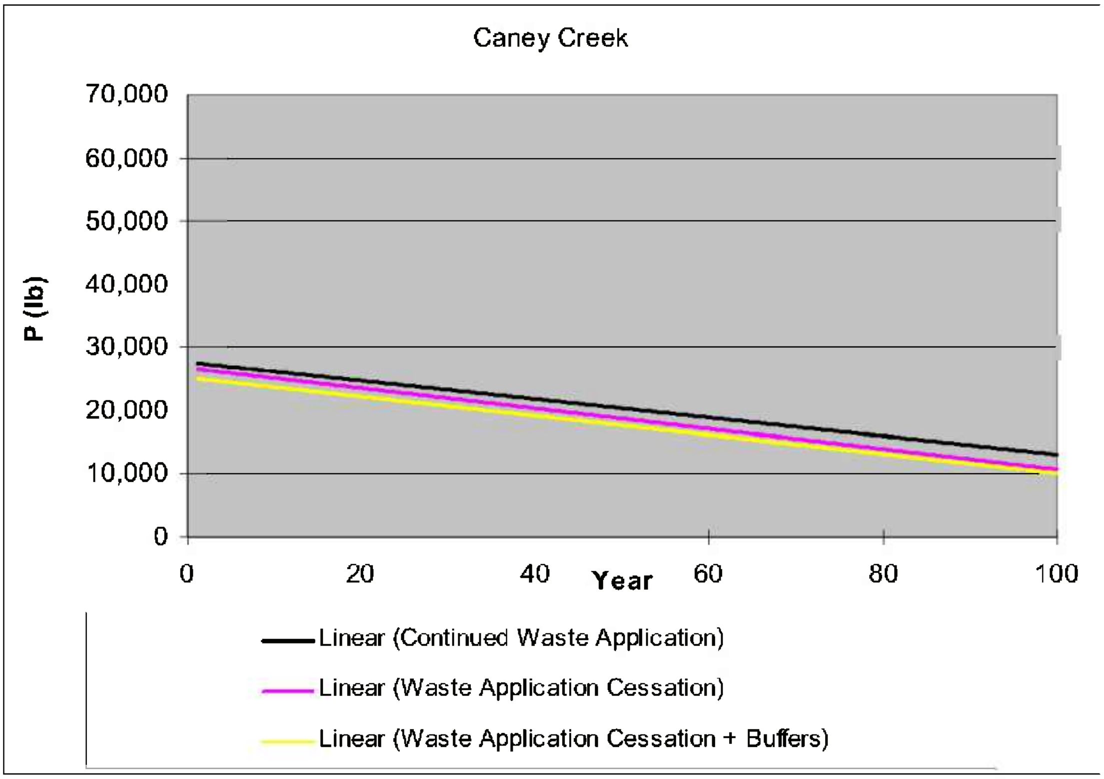


Figure 10.22. P Load Trends at Caney Creek for the Combination of Buffers Along Third Order and Larger Streams and Rivers and Poultry Waste Land Application Cessation in the IRW.

Table 10.8. P Loads for Poultry Waste Cessation and Poultry Waste Cessation Combined with Buffers Along Third Order and Larger Streams in the IRW. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

| | P Loads (lbs) | | | | | |
|---|---|---|---|---|---|---|
| Years | Tahlequah | Baron | Caney | Total | Total (Cessation Only) | Buffer Reduction (%) |
| 1-10 | 3,133,605 | 757,634 | 218,815 | 4,110,054 | 4,343,485 | 5.4 |
| 11-20 | 2,689,217 | 933,909 | 231,133 | 3,854,259 | 4,019,937 | 4.1 |
| 21-30 | 2,423,927 | 873,672 | 216,971 | 3,514,570 | 3,658,654 | 3.9 |
| 31-40 | 2,191,768 | 795,600 | 202,047 | 3,189,414 | 3,315,579 | 3.8 |
| 41-50 | 2,030,388 | 760,109 | 188,671 | 2,979,167 | 3,093,820 | 3.7 |
| 51-60 | 1,891,768 | 724,197 | 175,071 | 2,791,037 | 2,895,368 | 3.6 |
| 61-70 | 1,780,790 | 703,274 | 157,327 | 2,641,391 | 2,737,468 | 3.5 |
| 71-80 | 1,695,237 | 669,183 | 136,005 | 2,500,425 | 2,588,668 | 3.4 |
| 81-90 | 1,650,338 | 642,659 | 122,352 | 2,415,349 | 2,498,852 | 3.3 |
| 91-100 | 1,616,287 | 628,752 | 111,958 | 2,356,997 | 2,437,254 | 3.3 |

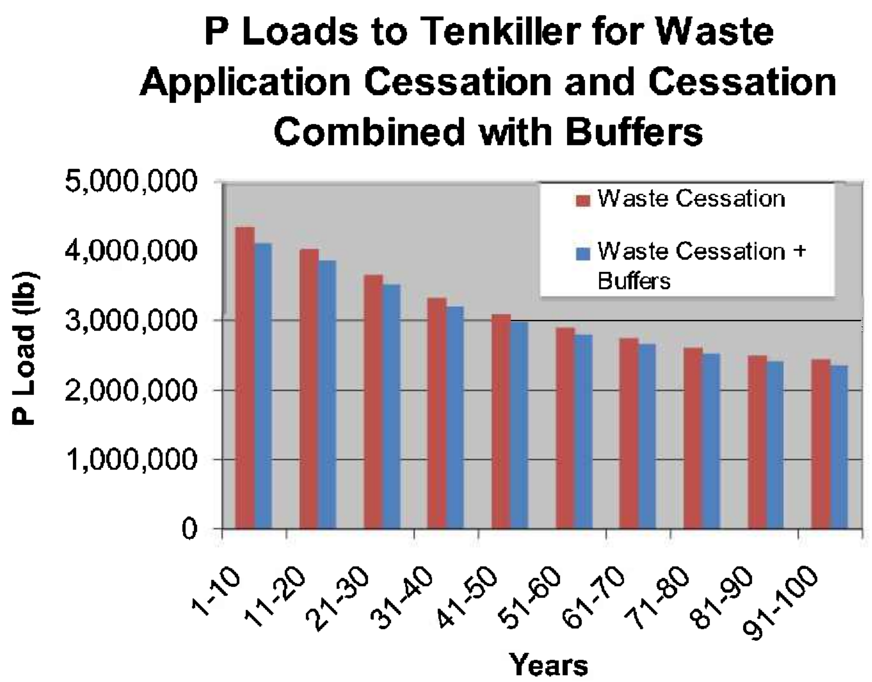


Figure 10.23. P Loads to Lake Tenkiller for Poultry Waste Application Cessation and Cessation Combined with Buffers Along Third Order Streams with Pastures. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

P loads were computed at three locations entering Lake Tenkiller (Tahlequah, Baron Fork at Eldon, and Caney Creek) for combined poultry waste land application cessation and 100 foot buffers placed along *all streams and rivers* with adjacent pasture (Figure 10.24 and Table 10.9). The buffers would provide approximately 10-13% additional reduction in P loads beyond cessation of poultry waste application in the IRW (Table 10.9).

Table 10.9. P Loads for Poultry Waste Cessation and Poultry Waste Cessation Combined with Buffers Along *All Streams* with Pasture in the IRW. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

| | P Load (lbs) | | | | | |
|---|---|---|---|---|---|---|
| Years | Tahlequah | Baron | Caney | Total | Total (Cessation Only) | Buffer Reduction (%) |
| 1-10 | 2,950,892 | 681,686 | 192,838 | 3,825,416 | 4,343,485 | 11.9 |
| 11-20 | 2,472,310 | 826,213 | 200,674 | 3,499,198 | 4,019,937 | 13 |
| 21-30 | 2,235,679 | 772,673 | 188,473 | 3,196,825 | 3,658,654 | 12.6 |
| 31-40 | 2,031,210 | 703,927 | 175,631 | 2,910,769 | 3,315,579 | 12.2 |
| 41-50 | 1,889,161 | 672,674 | 164,107 | 2,725,943 | 3,093,820 | 11.9 |
| 51-60 | 1,767,155 | 641,064 | 152,402 | 2,560,620 | 2,895,368 | 11.6 |
| 61-70 | 1,669,441 | 622,649 | 137,128 | 2,429,217 | 2,737,468 | 11.3 |
| 71-80 | 1,594,166 | 592,629 | 118,763 | 2,305,558 | 2,588,668 | 10.9 |
| 81-90 | 1,554,654 | 569,287 | 107,015 | 2,230,956 | 2,498,852 | 10.7 |
| 91-100 | 1,524,670 | 557,038 | 98,060 | 2,179,768 | 2,437,254 | 10.6 |

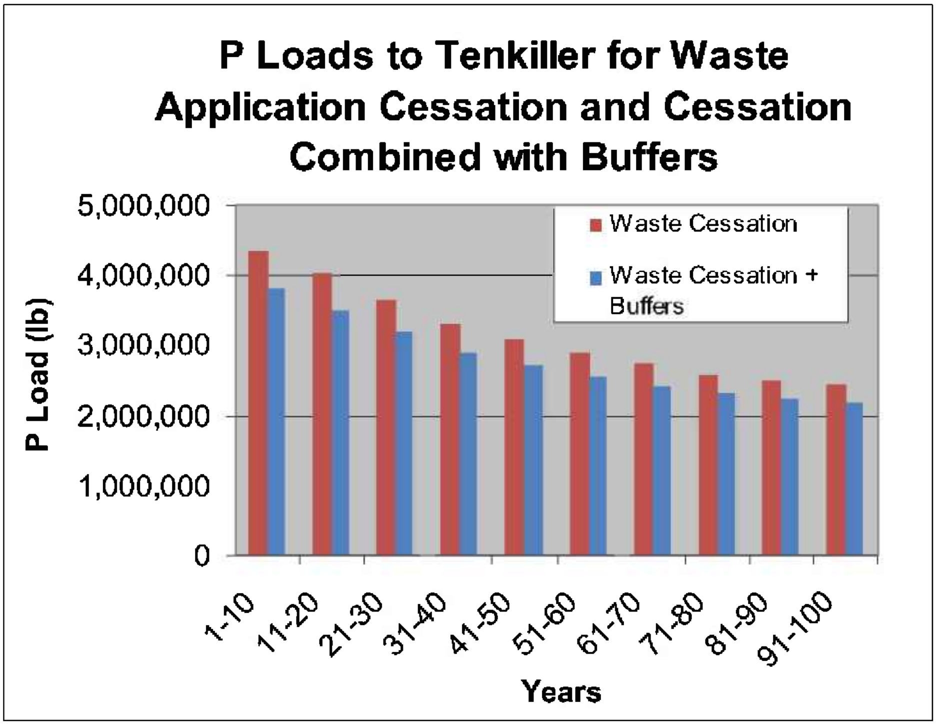


Figure 10.24. P Loads to Lake Tenkiller for Poultry Waste Application Cessation and Cessation Combined with Buffers Along *All Streams* with Pastures. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

*10.5 P Loads in Illinois River Watershed Streams and Rivers Assuming No Historic or Current Poultry Operations of the Defendants*

***P loads to Lake Tenkiller would be more than 275,000 lbs less than current levels (less than ½ of current levels) if poultry waste had never been disposed of in the IRW. It would take approximately 100 years of cessation of poultry waste application to return P loads in the IRW to what they would have been if no poultry waste land application had occurred.***

Figures 10.25-10.30 show the P loads at the three gauging stations (Tahlequah, Baron Fork at Eldon and Caney Creek) assuming no historic or current poultry operations in the IRW. This assumes no poultry industry and therefore no poultry waste application in the IRW (e.g., no poultry waste application ever). It also assumes present (2003 and later) WWTP P loads continuing into the future. This will show the present and future state of P loads in the IRW surface waters assuming the defendants poultry operations never existed.

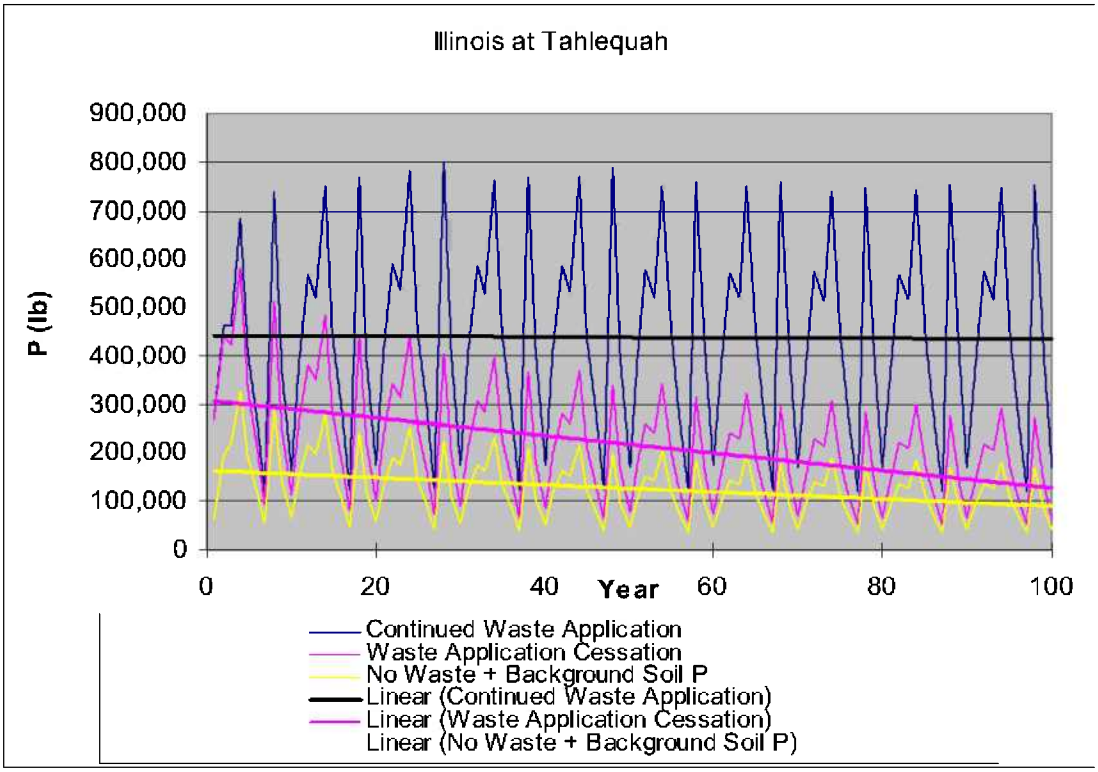


Figure 10.25. P Loads at Tahlequah for Background Soil P Levels with No Poultry Waste Application in the IRW.

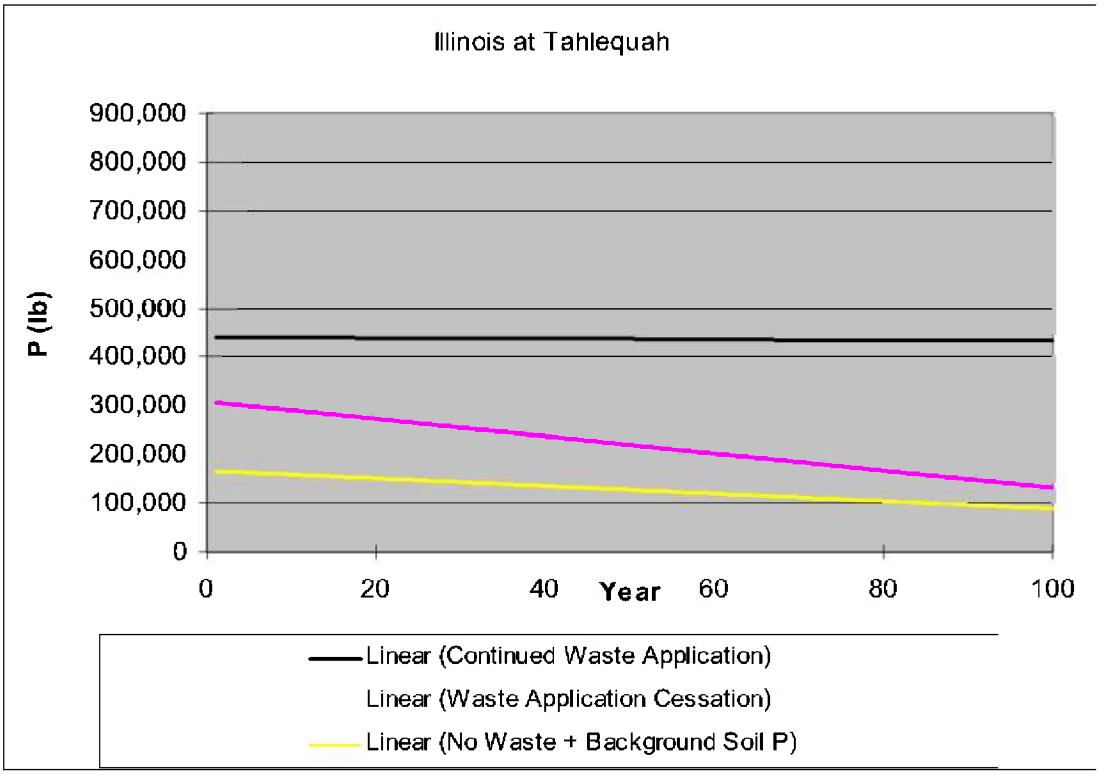


Figure 10.26. P Load Trend at Tahlequah for Background Soil P Levels with No Poultry Waste Application in the IRW.

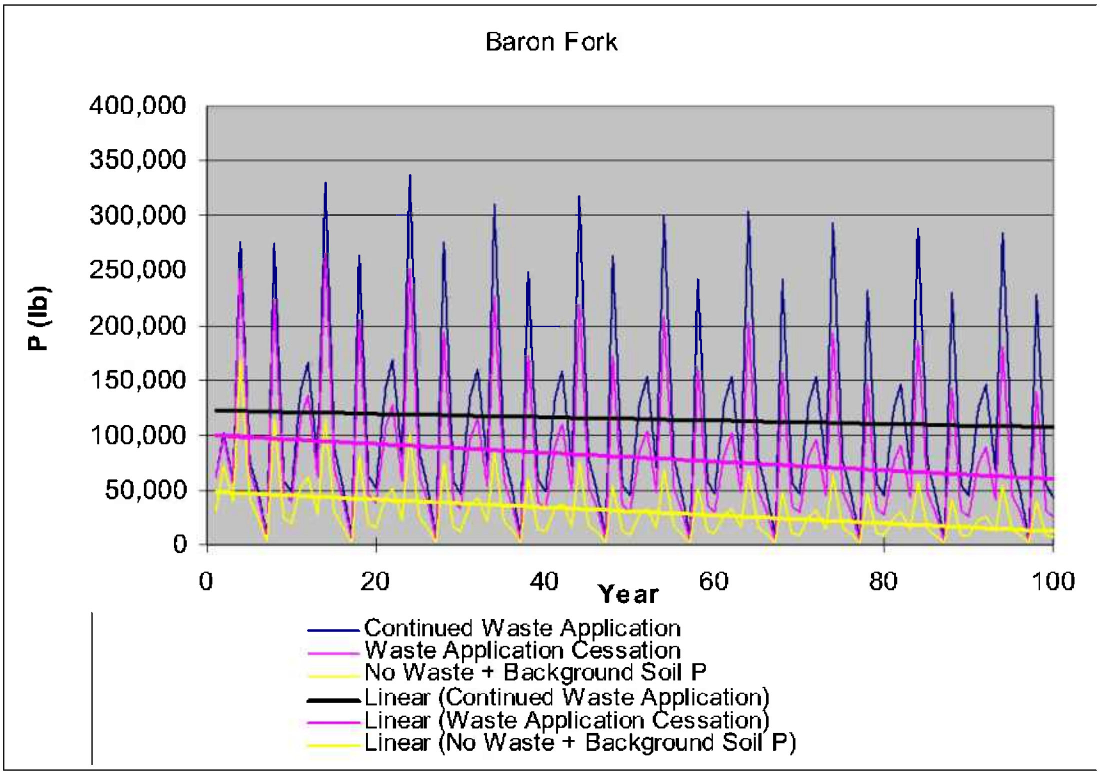


Figure 10.27. P Loads at Baron Fork near Eldon for Background Soil P Levels with No Poultry Waste Application in the IRW.

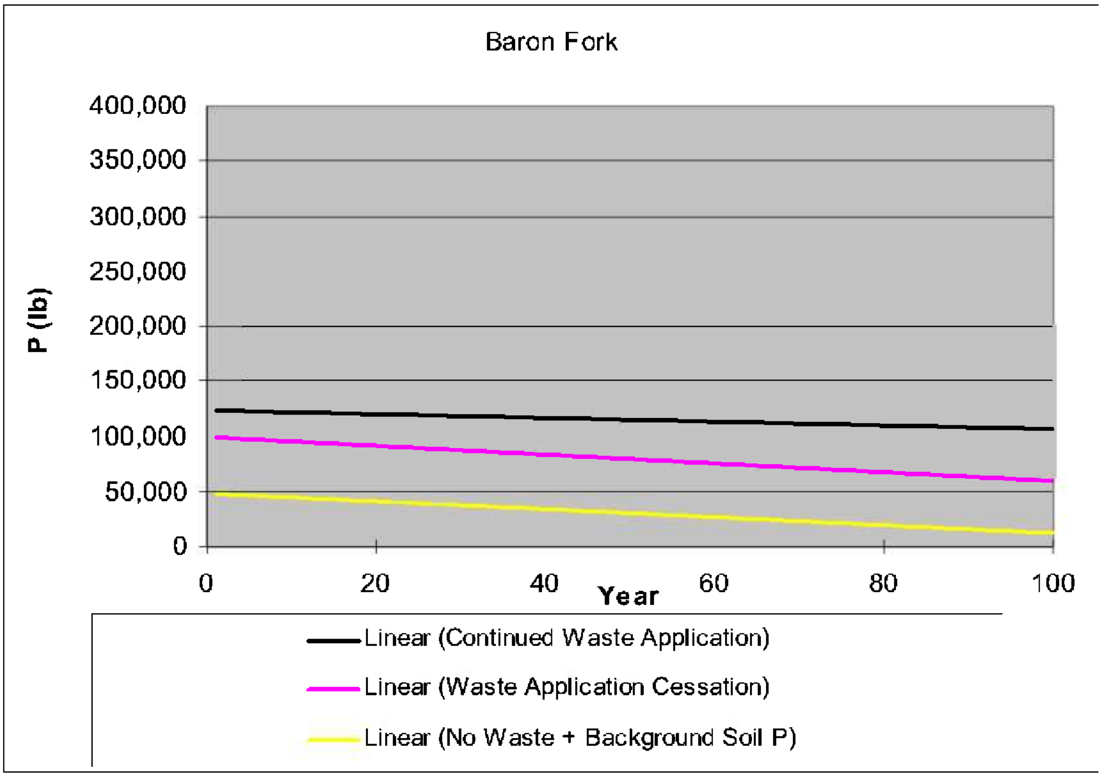


Figure 10.28. P Load Trend at Baron Fork near Eldon for Background Soil P Levels with No Poultry Waste Application in the IRW.

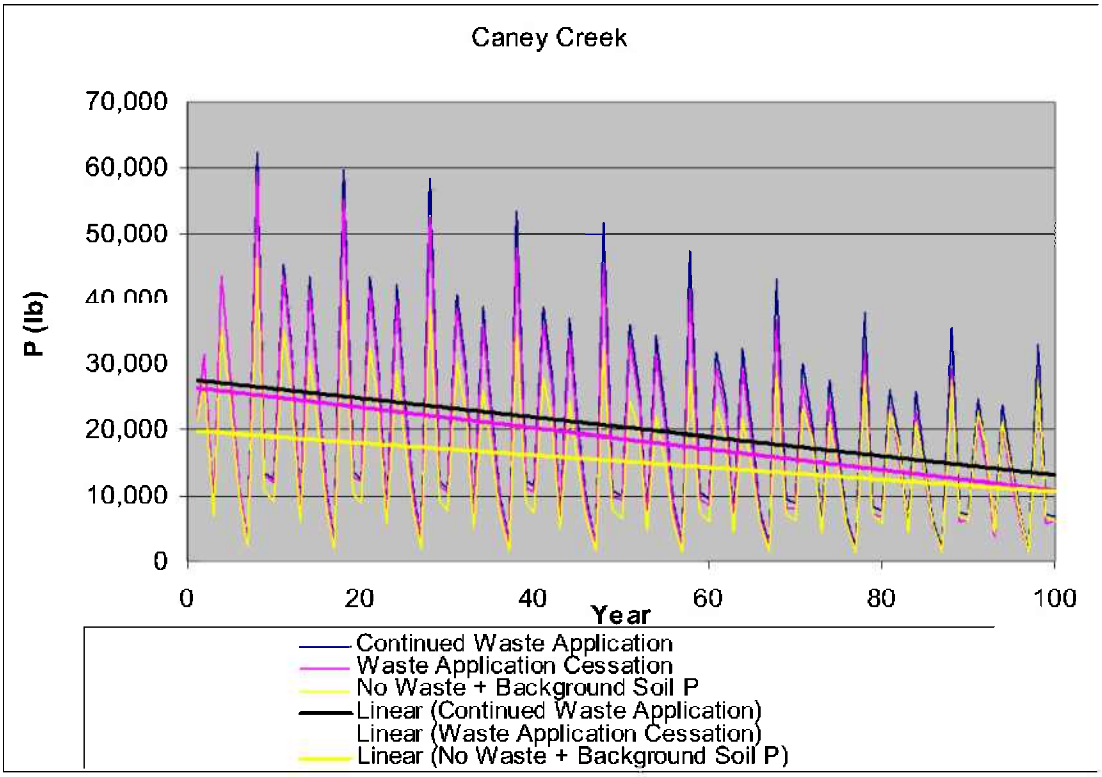


Figure 10.29. P Loads at Caney Creek for Background Soil P Levels with No Poultry Waste Application in the IRW.

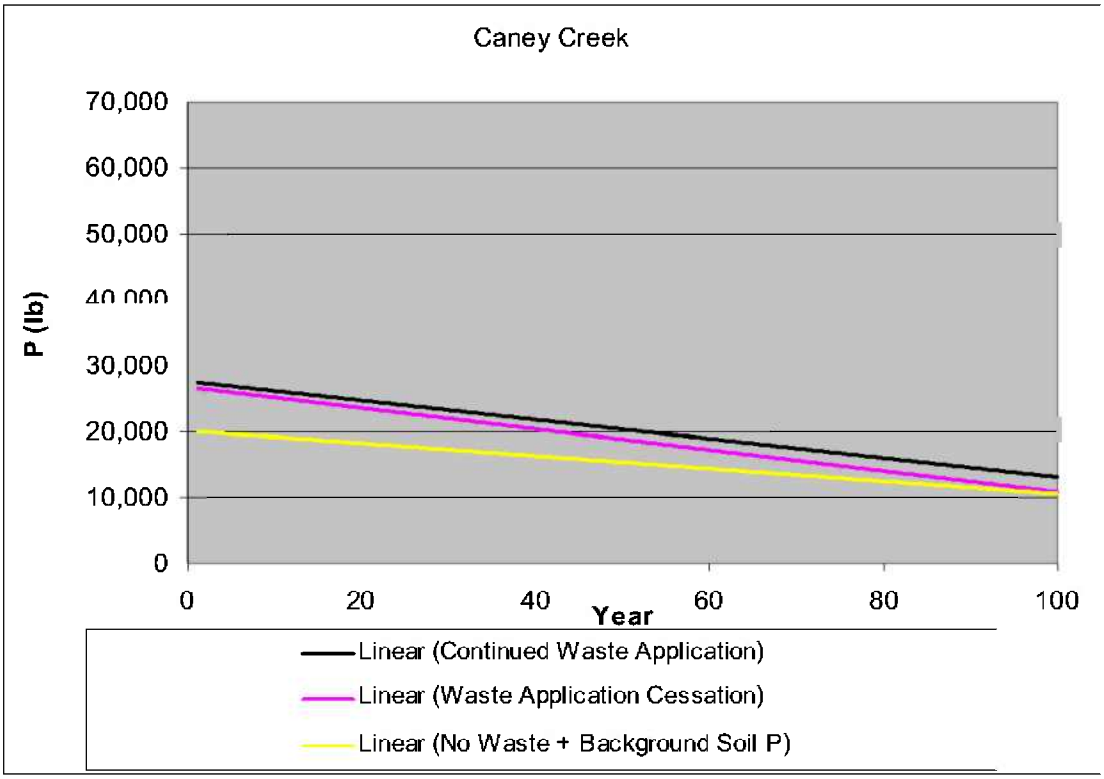


Figure 10.30. P Load Trend at Caney Creek for Background Soil P Levels with No Poultry Waste Application in the IRW.

The P loads for this scenario at Tahlequah indicate P loads would be substantially less (more than 275,000 lbs annually) than those for continued poultry waste application. The P loads for the background scenario would also remain approximately 150,000 lbs annually greater than poultry waste spreading cessation, narrowing to about 50,000 lbs annually after 100 years. This is due to the vast amount of P that has accumulated in IRW soils due to excessive poultry waste application (see Section 7. Phosphorus Mass Balance and see Johnson, 2008).

Differences between background P loads at Baron Fork near Eldon and continued poultry waste application would be approximately 75,000 lbs annually. The difference between background P loads and those with poultry waste application cessation would be approximately 50,000 lbs annually.

Differences in background P loads for the Caney Creek gauging location and continued poultry waste application would be small due to the limited poultry waste application in this watershed.

Table 10.10 summarizes the results for no historic or current poultry operations in the IRW and for poultry waste application cessation in the IRW. The P loads for no historic or current poultry operations in the IRW would decline over time due to P removal from the system (P loads to Lake Tenkiller and cattle). Even after 100 years, the waste cessation scenario indicates expected P loads to Lake Tenkiller would be greater than the P load for no historic or current poultry operations in the IRW (years 1-10). Thus, even after 100 years of poultry waste application cessation in the IRW, the elevated soil P levels due to historic poultry waste application would continue to contribute to P loads to IRW waters.

Table 10.10. P Loads to IRW Waters with No Poultry Waste Application and Total P Load to Lake Tenkiller for Poultry Waste Application Cessation. Weather Repeats Every 10 Years So Results Are Summarized in 10 Year Periods.

| | P Load (lbs) | | | | |
|---|---|---|---|---|---|
| Years | Tahlequah | Baron | Caney | No Application Total | Total (Cessation) |
| 1-10 | 1,593,185 | 517,044 | 183,305 | 2,293,534 | 4,343,485 |
| 11-20 | 1,577,197 | 418,569 | 191,028 | 2,186,795 | 4,019,937 |
| 21-30 | 1,416,532 | 360,511 | 177,237 | 1,954,279 | 3,658,654 |
| 31-40 | 1,316,867 | 305,908 | 162,427 | 1,785,203 | 3,315,579 |
| 41-50 | 1,232,647 | 268,748 | 149,734 | 1,651,129 | 3,093,820 |
| 51-60 | 1,155,226 | 245,471 | 136,380 | 1,537,077 | 2,895,368 |
| 61-70 | 1,112,297 | 238,307 | 132,631 | 1,483,235 | 2,737,468 |
| 71-80 | 1,077,848 | 225,995 | 130,736 | 1,434,579 | 2,588,668 |
| 81-90 | 1,057,895 | 208,819 | 128,060 | 1,394,774 | 2,498,852 |
| 91-100 | 1,044,273 | 192,647 | 127,000 | 1,363,920 | 2,437,254 |

*10.6 Historical P Loads in Illinois River Watershed Streams and Rivers*

***P loads to Lake Tenkiller since 1954 have increased at approximately 10,000 lbs per year. Poultry waste application in the IRW is responsible for approximately 6,600 lbs of this increase each year.***

P loads to the 3 gauging stations (Tahlequah, Baron Fork, and Caney Creek) were modeled using the same approach that has been used for modeling of results presented in prior sections. Soil P levels were assumed to be equivalent to current levels in Sequoyah County which would be considered equivalent to soil P levels for the entire watershed in 1950. WWTP P discharges were included as described in the WWTP section for 1950 through 1999 (Table 6.3). Poultry P applications to pastures in the IRW were based on historical poultry production in the watershed (Section 7).

Figures 10.31-10.33 show the modeled P loads from the IRW from 1950-1999. The trend line at the Tahlequah indicates P loads increase approximately 9,200 lbs/year and at Baron Fork by approximately 770 lbs/year. The Caney Creek watershed showed little change in P loads over this 50 year period, since its pastures received little poultry waste over this period.

Stow et al. (2001) computed historical nutrient loads in a watershed using a similar approach. Nutrient inputs to the watershed were computed for a more than 100 year period. WWTP nutrient inputs were computed using a similar approach as used within this report. Using the nutrient inputs and historical nutrient trends in observed river water, nutrient concentrations were computed.

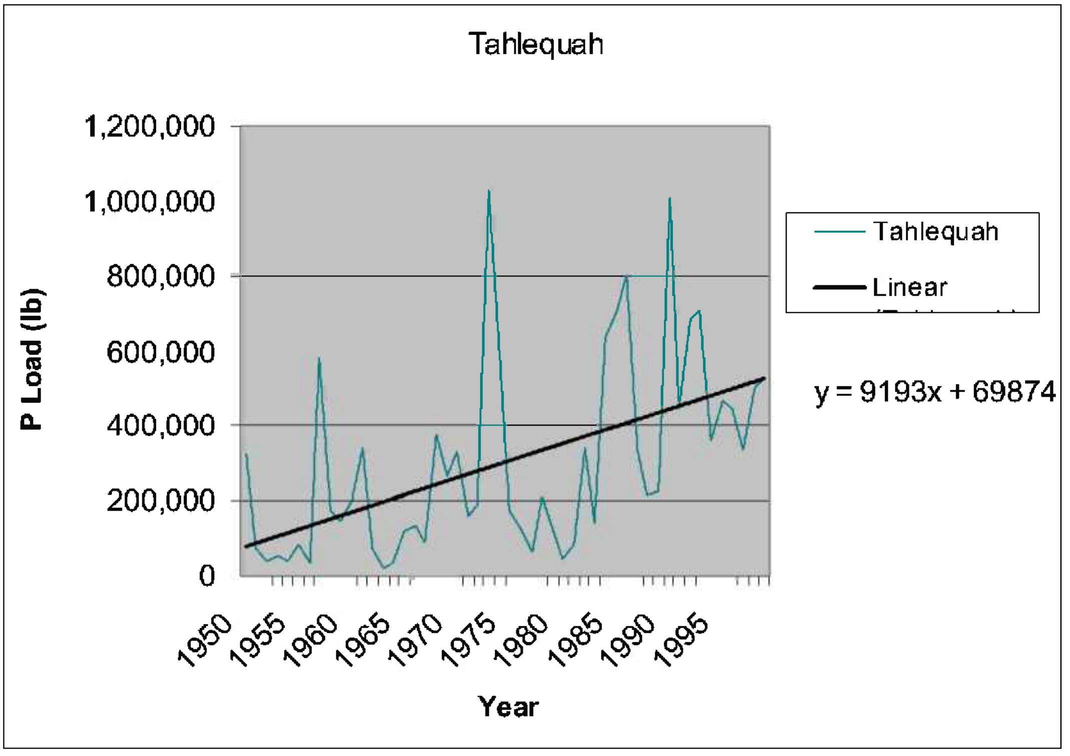


Figure 10.31. Modeled P Load and P Load Trend Line to Tahlequah from 1950 to 1999 Using Observed WWTP P Discharges and IRW Poultry Production

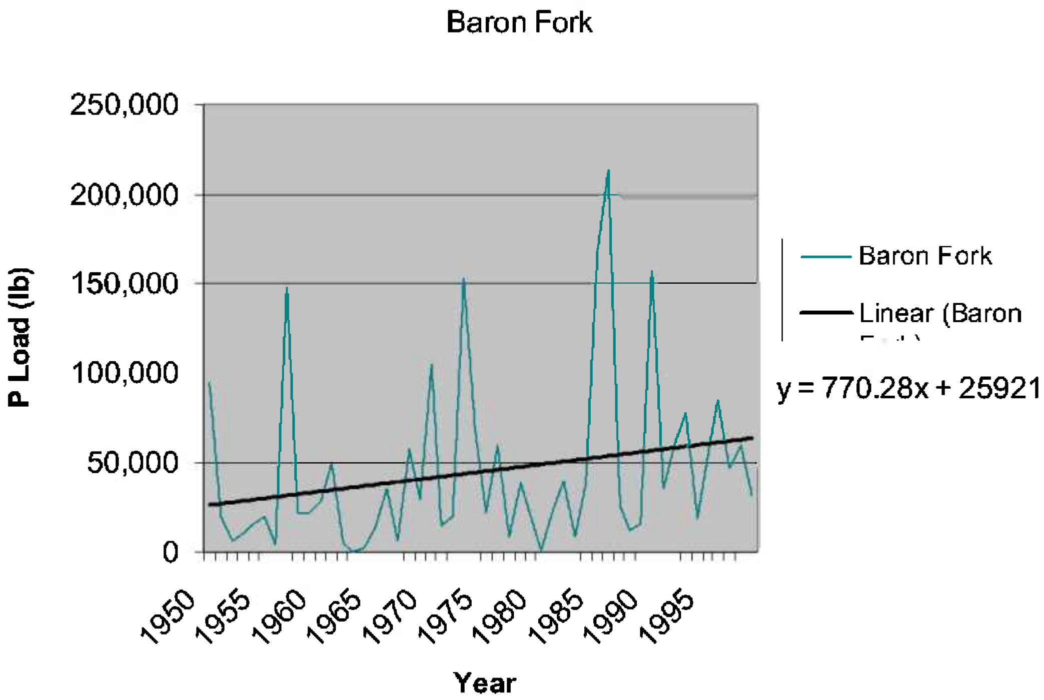


Figure 10.32. Modeled P Load and P Load Trend Line to Baron Fork near Eldon from 1950 to 1999 Using Observed WWTP P Discharges and IRW Poultry Production

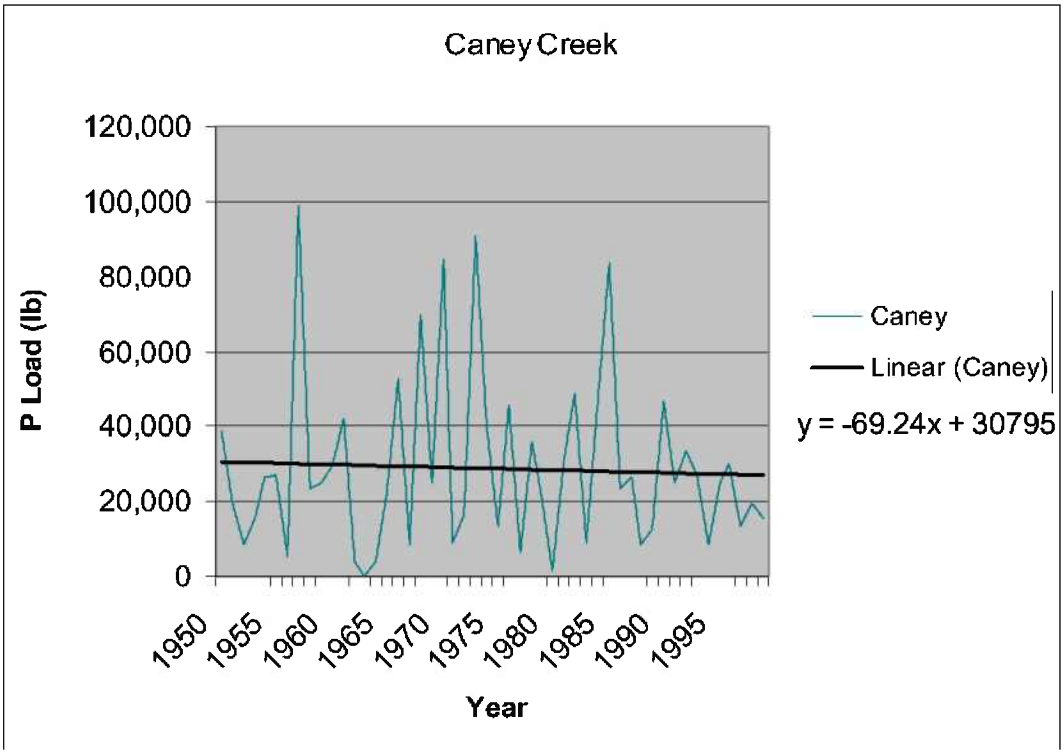


Figure 10.33. Modeled P Load and P Load Trend Line to Caney Creek from 1950 to 1999 Using Observed WWTP P Discharges and IRW Poultry Production

The NPS P loads from 1950 through 1999 are shown in Figures 10.34-10.36 for Tahlequah, Baron Fork at Eldon and Caney Creek. The WWTP P loads were not included in the results shown in Figures 10.34-10.36. The trend lines indicate P loads increase 6,700 lbs annually due to NPS sources. Nearly all of the increased P load is attributable to poultry waste application in the IRW (see P inputs into the IRW as documented in the Mass Balance Analysis in Appendix B).

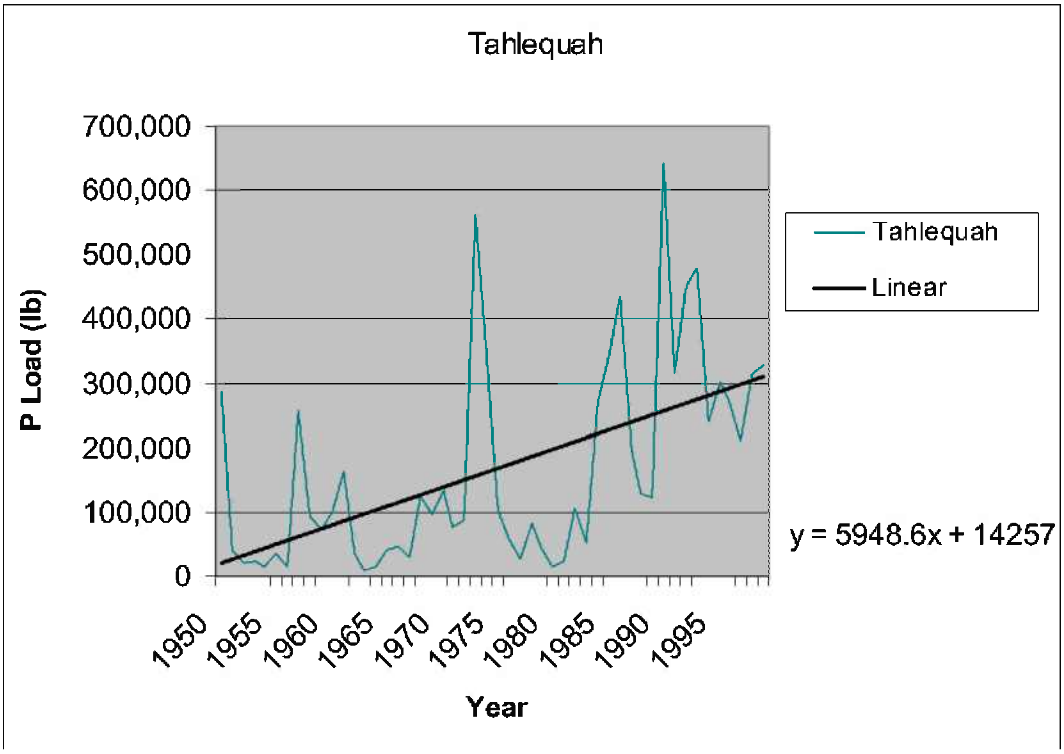


Figure 10.34. Modeled NPS P Load and NPS P Load Trend Line at Tahlequah from 1950 to 1999 Using IRW Poultry Production Data

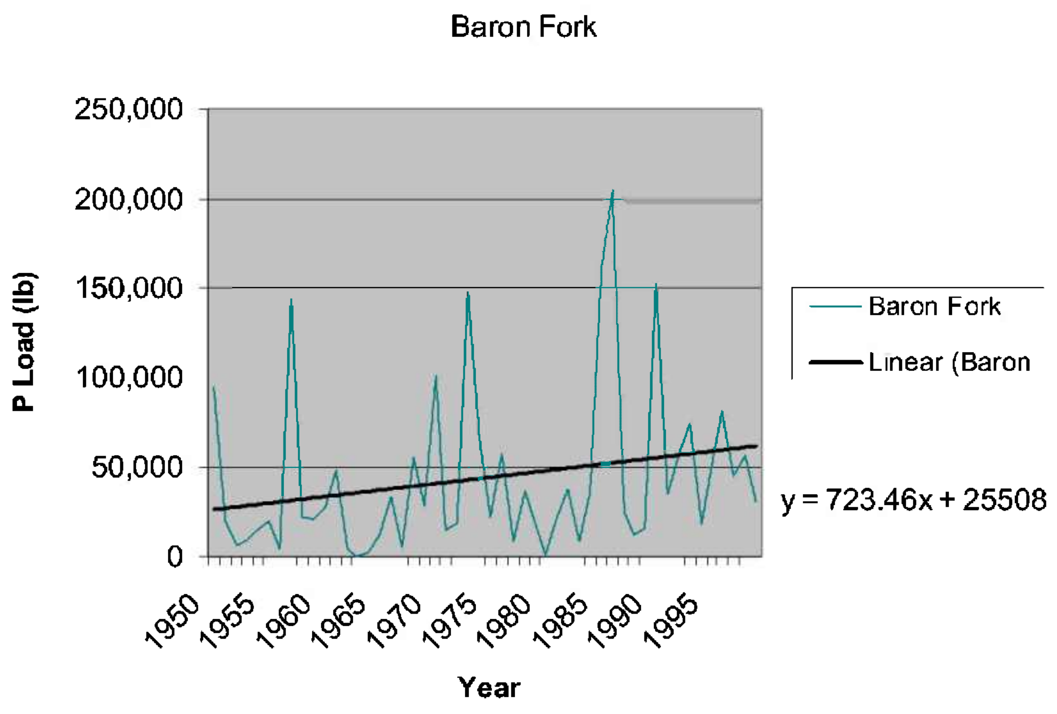


Figure 10.35. Modeled NPS P Load and NPS P Load Trend Line to Baron Fork Near Eldon from 1950 to 1999 Using IRW Poultry Production Data

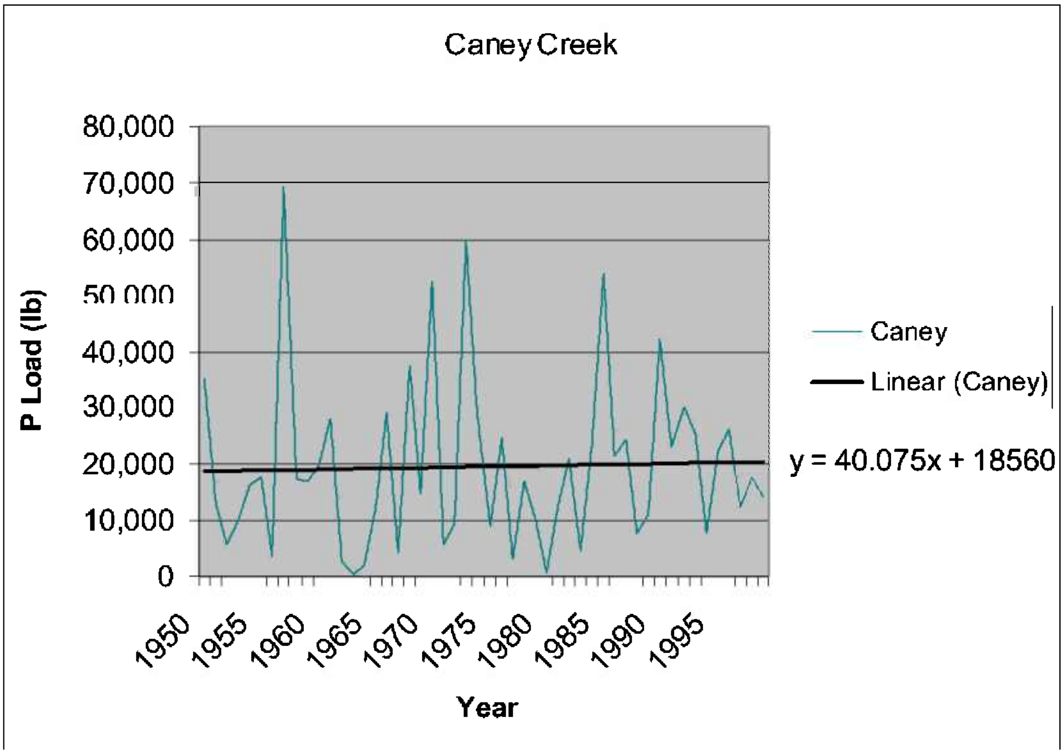


Figure 10.36. Modeled NPS P Load and NPS P Load Trend Line to Caney Creek from 1950 to 1999 Using IRW Poultry Production Data

Average annual historical P concentrations for March-June and July-September were computed for the Tahlequah and Baron Fork locations in support of Dr. Jan Stevens' analysis. Average concentrations were computed based on daily concentrations for each of the analyses periods. Figures 10.37 and 10.38 show P concentrations at Tahlequah for March-June and July-September, respectively. Average concentrations were computed based on daily concentrations for each of the analyses periods. Figures 10.39 and 10.40 show P concentrations at Baron Fork for March-June and July-September, respectively. The P concentration trends for these periods are similar to annual P load trends.

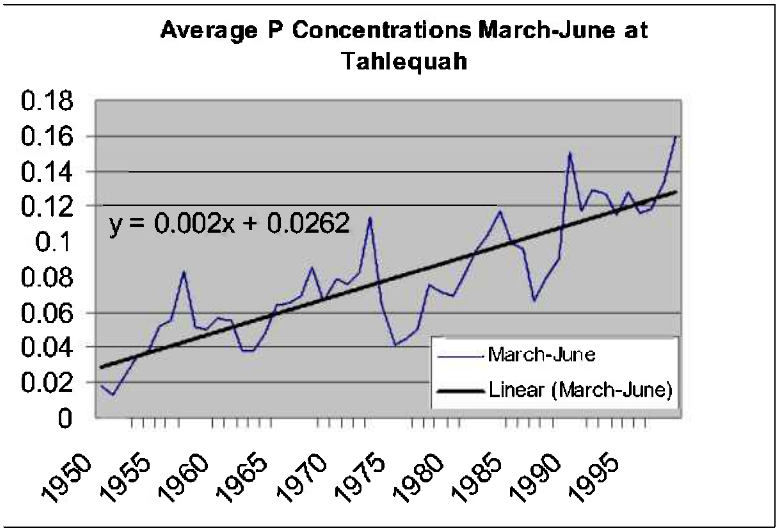


Figure 10.37. Average P Concentrations for March-June Annually at Tahlequah from 1950 Through 1999 Using IRW Poultry Production Data

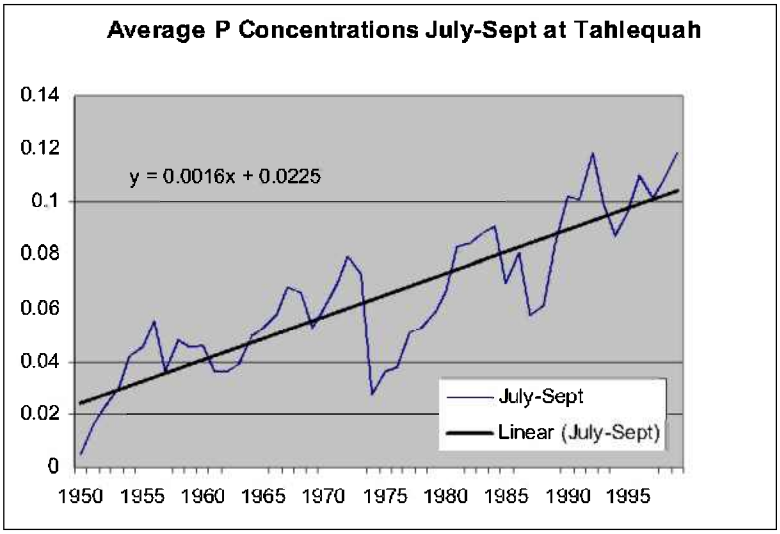


Figure 10.38. Average P Concentrations for July-September Annually at Tahlequah from 1950 Through 1999 Using IRW Poultry Production Data

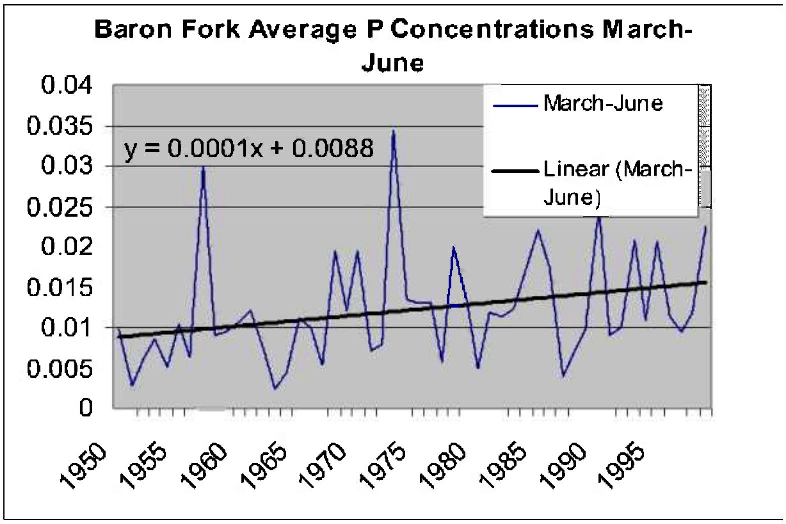


Figure 10.39. Average P Concentrations for March-June Annually at Baron Fork from 1950 Through 1999 Using IRW Poultry Production Data

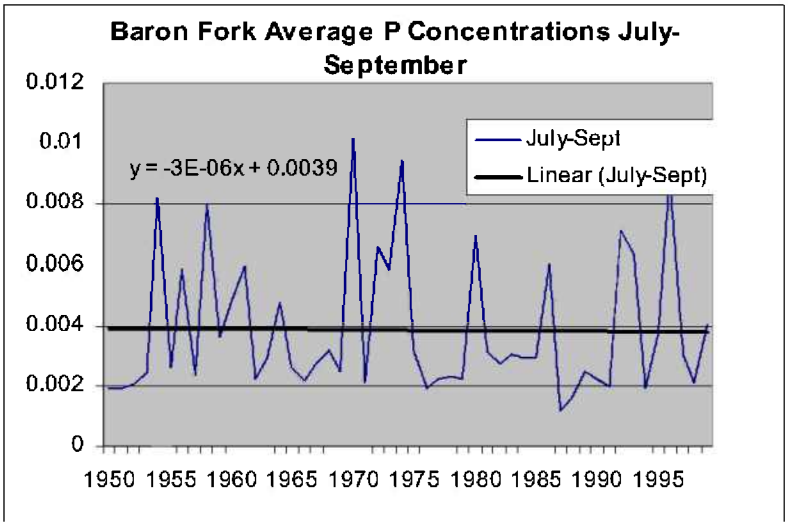


Figure 10.40. Average P Concentrations for July-September Annually at Baron Fork from 1950 Through 1999 Using IRW Poultry Production Data

*10.7 Statistical Analysis of P Loads*

A statistical analysis of the modeled P loads was conducted to determine if the P loads for the scenarios were statistically different. Both parametric (ANOVA) and nonparametric (Kruskal-Wallis Test) analyses were completed for each of the scenarios at each of the sites (Tahlequah, Baron Fork, and Caney).

For each location, boxplot exploratory data analysis (EDA) was used to gain insight of the distribution of the daily P losses. This was done to ensure that assumptions and constraints of Gaussian statistical procedures were not violated. For example, the validity of parametric tests such as Analysis of Variance (ANOVA) requires that the data follow a Gaussian distribution with constant variance (Montgomery, 2004). If the model assumptions of normality and constant variance are violated, then nonparametric testing procedures are usually more robust. However, in practice, an alternative approach to nonparametric tests involves the application of logarithmic transformation to the data; thereby, facilitating the use of parametric test for further analysis. This procedure stabilizes the variance while creating a distribution closer to normality. It is useful especially in cases where the data set have large or very small values. The data were log transformed for use with the parametric tests.

The ANOVA analyses and multiple comparison tests were generated using SAS/STAT® software, version 9.1.3 (SAS, 2004). The test statistics was based on the following hypothesis:
$H_0$: $\tau_1 = \tau_2 = \tau_3 = \tau_4 = \tau_5 = \tau_6 = 0$ versus $H_1$: at least one treatment is not equal
where,

$H_0$ = null hypothesis
$H_1$ = alternative hypothesis
$\tau_1$= effects of continue waste application
$\tau_2$= effects of waste application cessation
$\tau_3$= effects of growth
$\tau_4$= effects of no waste ever
$\tau_5$= effects of waste cessation and buffer along third order and above streams
$\tau_6$= effects of waste cessation and buffers along all streams

Tukey multiple comparison indicates that P loads for each of the six scenarios for Tahlequah and Baron Fork were statistically different (Tables 10.11 and 10.12). For Caney Creek scenarios, the P loads for 'Waste Cessation + Buffer All' (waste application cessation and buffers along all streams and rivers) and 'No Waste Background P' (no poultry waste application ever in the watershed) were not significantly ($\alpha < 0.05$) different; however, all other P loads for Caney Creek scenarios were significantly different from each other (Table 10.13).

The statistical analyses indicate the continued growth in the poultry industry within the IRW and land application of poultry waste would provide the largest P loads, continued poultry waste application would provide the next largest P loads, and cessation of land application would provide the next largest loads. Cessation of waste application with buffers along third order streams would provide the next largest loads and waste application cessation with buffers along all streams would provide the next largest P loads. The lowest P loads occur for the case in which no poultry waste application was ever applied within the IRW.

Table 10.11. Statistical summary of phosphorus scenarios based on daily P output for Illinois River at Tahlequah

| Treatment | N | Mean Daily P Load (lb) |
|---|---|---|
| Continue Waste Application | 36525 | 543.69[a] |
| Waste Cessation | 36525 | 270.00[b] |
| 50 Year Growth | 18300 | 876.26[c] |
| No Waste Background P | 36525 | 156.44[d] |
| Waste Cessation + Buffer | 36525 | 262.07[e] |
| Waste Cessation + Buffer All | 36525 | 244.51[f] |

Note: Means with the same letter are not significantly different at the 5% level.
N is number of observations (daily P loads)

Table 10.12. Statistical summary of phosphorus scenarios based on daily P output for Baron Fork near Eldon

| Treatment | N | Mean Daily P Load (lb) |
|---|---|---|
| Continue Waste Application | 36525 | 141.64[a] |
| Waste Cessation | 36525 | 99.16[b] |
| 50 Year Growth | 18300 | 172.58[c] |
| No Waste Background P | 36525 | 37.04[d] |
| Waste Cessation + Buffer | 36525 | 93.00[e] |
| Waste Cessation + Buffer All | 36525 | 82.46[f] |

Note: Means with the same letter are not significantly different at the 5% level.
N is number of observations (daily P loads)

Table 10.13. Statistical summary of phosphorus scenarios based on daily P output for Caney Creek

| Treatment | N | Mean Daily P Load (lb) |
|---|---|---|
| Continue Waste Application | 36525 | 25.18[a] |
| Waste Cessation | 36525 | 23.13[b] |
| 50 Year Growth | 18300 | 29.63[c] |
| No Waste Background P | 36525 | 18.89[d] |
| Waste Cessation + Buffer | 36525 | 21.86[e] |
| Waste Cessation + Buffer All | 36525 | 19.06[d] |

Note: Means with the same letter are not significantly different at the 5% level.
N is number of observations (daily P loads)

*10.8 Allocation of P to Sources*

***Poultry waste land application in the IRW is a substantial contributor (45% between 1998 and 2006 and 59% between 2003 and 2006) to P loads to Lake Tenkiller, representing the largest P source. WWTP P loads are the second largest contributor to P loads to Lake Tenkiller. Poultry plant discharges to WWTP represent a significant portion of WWTP P loads.***

The P contribution of each significant source was determined using the IRW modeling (Appendix D). The P allocation to each source is shown in Tables 10.14 and 10.15. P loads from poultry waste application within the IRW represents 45% of P loads to Lake Tenkiller between 1998 and 2006. Following a change in WWTP technology that reduced WWTP P discharges, poultry waste application in the IRW was responsible for 59% of P loads to Lake Tenkiller for years 2003-2006.

Table 10.14. IRW P Load Allocation to Sources

| | WWTP | Forest | Crop | Urban | Pasture |
|---|---|---|---|---|---|
| 1998-2006 | 30 | 1 | < 1 | 7 | 62 |
| 2003-2006 | 15 | 1 | < 1 | 7 | 76 |

Table 10.15. IRW P Load Allocation to Sources

| | WWTP | | | | | Pasture | | |
|---|---|---|---|---|---|---|---|---|
| | Poultry | Nonpoultry | Forest | Crop | Urban | Cattle Near Streams Only | Poultry Only | Swine, Dairy, Background |
| 1998-2006 | 10 | 20 | 1 | < 1 | 7 | 6 | 45 | 11 |
| 2003-2006 | 3 | 12 | 1 | < 1 | 7 | 6 | 59 | 11 |

WWTP discharges are the second largest contributor of P loads representing 30% of P loads between 1998 and 2006 (Table 10.14). A portion of the WWTP P load is attributable to poultry processing discharge to the Springdale WWTP as described in Section 6. Poultry processing discharges released by the Springdale WWTP represent 10% of total P loads to Lake Tenkiller between 1998 and 2006 and 3% of P loads between 2003-2006 (Table 10.15).

Pasture with swine and dairy waste application and background P from pastures is the third largest P load to Lake Tenkiller (Tables 10.14 and 10.15). Runoff from urban areas is the fourth largest contributor at 7% of P loads (Tables 10.14 and 10.15). Cattle in and near streams contribute 6% of P. However, this is almost all poultry P because cattle only facilitate the transport of P (discussion of cattle contributions follows in the next section). Other sources of P loads are responsible for 1% or less of P loads to Lake Tenkiller.

These results are consistent with other reports for the IRW (Section 2 of this report) and with studies for similar watersheds. The Draft TMDL for the IRW and Lake Tenkiller (USEPA Region 6 and Department of Environmental Quality State of Oklahoma, 2001) identified pastures on which poultry waste is applied as being responsible for 56% of P to Lake Tenkiller. Smith et al. (1997) indicated more than 78% of P loads in the IRW were attributable to livestock waste. Storm and White (2003) estimated that poultry waste was responsible for more than 49% of P loads in the Eucha Spavinaw Watershed that has similar conditions to the IRW.

*10.8.1 Contribution of Cattle in and Near Streams*

***Cattle in the IRW recycle P brought into the IRW to feed poultry that is excreted by poultry and land applied to pastures within the IRW. Although the P contribution of cattle is from poultry waste, cattle accelerate the movement of P into IRW streams and rivers when they excrete waste in and near IRW streams. Six percent of P loads to Lake Tenkiller result from cattle in and near IRW streams.***

Cattle within the Illinois River Watershed are recycling poultry waste P that has been applied to pastures. For example, nutrients contained in beef cattle manure were ignored by Slaton et al. (2004) as they indicate "a large proportion of these nutrients are obtained from forage and deposited directly (i.e., recycled) to pastures during grazing rather than collected in lagoons or stockpiled from confined animal production facilities." Cattle largely consume grass from pastures and hay produced in the watershed, and thus P is not imported into the watershed in the form of cattle feed with the exception of a small amount of supplemental feed (Section 7 and Appendix B).

The amount of cattle waste and P in that waste were computed as described in Appendix E. Cattle in the IRW produce approximately 319,000 tons of waste annually (dry weight basis). This waste contains approximately 7.8 million lbs of P of which nearly all is recycled P from poultry waste, with the exception of 210,000 lbs of this P that is imported in cattle supplement (Section 7).

Cattle can accelerate the loading of P to surface water when they excrete waste in or near streams. The amount of P deposited by cattle in or near streams was calculated based on the length of streams, pasture near streams, average pasture sizes, cattle in the watershed, and excretion data for cattle in and near streams. Calculated P deposited by cattle in or near (within 10 meters) streams is up to 35,594 lbs/yr (6% of P loads to Tenkiller). Details of the calculations are provided in Appendix F.

*10.8.2 Contribution of Septic Systems*

***The contributions of septic systems to P loads in the IRW are negligible*** based on the IRW Mass Balance analysis (Section 7 and Appendix B), analysis of P loads from sub-basins within the IRW for 2005 and 2006 (Olsen, 2008 and Appendix G), and analyses of IRW septic systems (e.g., Oklahoma Department of Environmental Quality (1997); Estimated Maximum Contribution of Phosphorus from Septic Systems, Illinois Basin, 1997).

## 11. **References**

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**Rate of Compensation**

Dr. Engel's rate of compensation for this case is $165 per hour.